A Further Look at Technologies and Capabilities for Stabilization and Reconstruction Operations

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Chapter 1. Introduction

In a previous study on technology for stabilization and reconstructions operations, hereafter SRO(I), the authors[1] evaluated current stabilization and reconstruction (S&R) operations requirements and identified for Dr. Tom Killion, the Army Science and Technology (S&T) Executive, areas in which Army capabilities could be improved with advanced technologies. Stabilization and reconstruction operations establish, retain, and exploit security and control over areas, populations, and resources to employ military capabilities to restore essential services and facilitate the reestablishment of civil order and authority.[2] They involve both coercive and cooperative actions and occur before, during, and after offensive and defensive operations.

The S&R[3] mission has become no less pressing for the Army since the first report was written. America remains heavily involved in Iraq and Afghanistan. These two conflicts, whatever their substantial differences, demand a force trained and equipped to move back and forth between combat operations and civil administration, from coercive to cooperative action, from responding with lethal force to responding with a greeting in a foreign language. Such requirements will not fade with these wars' conclusions. The Department of Defense (DOD) has recognized S&R as an enduring responsibility, stating in Directive 3000.05 that "stability operations are a core U.S. military mission…" to be "…given priority comparable to combat operations and be explicitly addressed and integrated across all DOD activities…"[4] No matter what the nature of future conflicts, victory hinges not only on defeat of opposition military forces but on the creation of a sustainable peace shaped by U.S. interests. The full spectrum of operations, from war planning to combat to aftermath, must be informed by the ultimate need to successfully execute stabilization and reconstruction.

Our first study principally identified technology needs generated by operations in Iraq and Afghanistan. Among the areas needing renewed emphasis were: improvised explosive device (IED) defeat mechanisms; longer range, non-line-of-sight communications; blue force tracking down to the dismounted soldier especially in a global positioning system (GPS)-denied environment; an on-the-ground biometric identification device, and fielding "hover and stare" unmanned aerial vehicle (UAV) assets for use at the platoon level. The findings were based primarily on field surveys and interviews conducted at the National Defense University (NDU), Fort Knox, Kentucky, and Ft. Hood, Texas, of military officers returning from Iraq and Afghanistan.

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[1] Richard Chait, Albert Sciarretta, and Dennis Shorts, "Army Science and Technology Analysis for Stabilization and Reconstruction Operations," *Defense and Technology Paper* 37 (Washington, DC: Center for Technology and National Security Policy, National Defense University, October 2006).
[2] FMI F-O.1, Appendix A, A-4.
[3] The stabilization operations lexicon has evolved and remains diverse. A studied reading of the literature leads to the conclusion that most of the various conceptualizations are in harmony. For the purposes of this report we will intend Stabilization and Reconstruction (S&R) operations to have meaning parallel to the DOD term Stability, Security, Transition, and Reconstruction (SSTR) Operations.
[4] "Military Support for Stability, Security, Transition, and Reconstruction (SSTR) Operations," Department of Defense Directive 3000.05

The present study resumes where the first left off, expanding on identifying capability needs and possible technology solutions to the S&R problems facing the force today and in the future. The following chapter-by-chapter sketch provides a brief look at how this will be accomplished.

- Chapter 2 updates the findings of SRO(I) with a new data collection effort on capability needs for S&R operations.
- Chapter 3 broadens and deepens our understanding of S&R capability needs with a *use case analysis* approach. Three scenarios typical of S&R missions are used to establish a catalogue of relevant capabilities. This analysis echoes needs established through the primarily questionnaire-based data collection in SRO(I) and the update in Chapter 2 and identifies some needs that those efforts did not highlight.
- Chapter 4 is a warfighter[5] assessment of the findings of the use case analysis in Chapter 3. By vetting the analysis results with warfighters with recent S&R experience, we were able to focus the list of S&R capability needs and deepen our understanding of the issues at hand. The warfighters also offered their informed judgments on the pluses and minuses of proposed technical solutions to the identified needs.
- Chapter 5 elaborates on an important subset of the gaps identified through the various data collection efforts in SRO(I), Chapter 2, Chapter 3, and Chapter 4: those pertaining to battle command. While these efforts highlighted a host of technology needs for S&R, a significant number of them dealt with communications, command and control, situational awareness, and other battle command-related capability needs. Battle command is a discipline that applies to the full spectrum of operations, not just S&R, and technologies to support battle command are similarly versatile. There are, however, battle command concerns particular to S&R, and it is important that future technologies take these into account. This chapter will discuss battle command doctrine and illuminate future technology needs in this area
- Chapter 6 surveys technology areas that could address some of the identified S&R capability needs. We review recent research efforts in six areas: electronics, sensors, power sources for the individual soldier, basic research in advanced materials, robotics, combat casualty care, and system level battle command technologies. Some of these have elements that could benefit the force in the near term, but the potential of most will not be fully realized without significant additional development work. These technical disciplines have a range of military applications including, but not limited to, S&R operations.

While many of the capability gaps we cite have future importance to S&R operations in various parts of the world, we readily acknowledge that the gaps with which this report is concerned are heavily influenced by Iraq and Afghanistan, which represent just two of many possible types of future S&R operations. The technology requirements are focused in large part on combat, and in particular on urban S&R operations. In other, future S&R operations there may be less pressing security needs and less focus on counterinsurgency operations. A survey of veterans of deployments to the Balkans or Haiti, for instance, might have generated a different set of technology and capability priorities. While the use cases aim to cover a broad, generic spectrum

[5] The term *warfighter* encompasses all Army military personnel. It does not necessarily indicate a role in direct combat, but applies to all military personnel engaged in the full spectrum of related activities, including stabilization and reconstruction.

of operations, and so expand the list of needed capabilities beyond those at the forefront of the minds of today's warfighters, they too are informed by the nation's current conflicts.

Nevertheless, to the degree that Iraq and Afghanistan color this report's focus, they in no way devalue it. While there is danger inherent in planning to fight the last war, it is equally risky to neglect to learn from the past. Further, many of the technologies and capabilities discussed in the present report have application across a range of possible scenarios, from high-intensity urban combat to post-conflict operations in permissive environments to humanitarian relief to civil support operations conducted within the United States.

Chapter 2. Stabilization and Reconstruction Report I Update

This chapter updates the data acquired and analyzed in SRO(I). The findings in SRO(I) were based primarily on field surveys conducted at NDU and supplemented by some interviews at Ft. Hood, Texas, and Fort Knox, Kentucky. At NDU, the surveyed military officers (largely lieutenant colonels and colonels) were returning from Iraq and Afghanistan and were enrolled as students in either the Industrial College of the Armed Forces (ICAF) or the National War College (NWC). We did not hear from the combat casualty care community during SRO(I) but did so in SRO(II). Therefore, we added a section on this topic in Chapter 6 based on follow-up interviews. Though the research effort described in SRO(I) yielded some valuable information on the Army's S&R capability needs, we were mindful that our data was drawn from a relatively small subset of officers. Our first step in undertaking the present report was to repeat our earlier study to see if results would vary significantly if we questioning different warfighters who (generally) served in Iraq and Afghanistan at a different time than those questioned for SRO(I). We conducted another survey of NDU students, again supplemented by warfighter interviews at Ft. Hood. This new effort produced results very similar to our findings in SRO(I). The issues presented below are covered in the same order they were presented in SRO(I).

The first topic had to do with the broad category of battle command (BC), which is comprised of several sub-areas having to do with command and control (C2). Prominent among these sub-areas is the issue of *tracking friendly forces*. Technology in terms of tracking "Blue" forces has been improved upon and continues to be fielded at a rapid pace. As was pointed out in the SRO(I) report, the Command Post of the Future (CPOF) was in extensive use at the brigade and above levels. Warfighters also stated that they had great utility with the Blue Force Tracker (BFT), along with Force XXI Battle Command, Brigade and Below (FBCB2). There continues to be an issue with tracking dismounted soldiers. It was stated that, while on patrol, C2 of dismounted warfighters was often handled through voice communications (which, in urban environments such as Baghdad, was intermittent). Some warfighters with experience in urban operations expressed some concern with the idea of scaling BFT down to the individual soldier level—a visual depiction at the Battalion Tactical Operations Center (BNTOC) level would look chaotic. This concern is noted, and is being addressed at the program management (PM) offices with purview over this issue area. Granularity in depiction of BC must be scaled for the appropriate echelon, with lower echelon units (most likely, the platoon) "zooming" down to the individual. Vehicle-based BFT is useful and crucial, but extending BC down to the small unit leader will be crucial to conducting operations in complex environments.

In terms of the need for an *integrated S&R operational planning and execution C2 system,* there continues to be a challenge in knitting together the various elements involved in S&R operations. It was noted that although military cooperation with civilian government agencies has improved—especially with the United States Agency for International Development and the State Department—much work still needs to be done on effectively coordinating efforts and creating a common operating picture (COP) on information systems such as CPOF. The Provincial Reconstruction Team (PRT) model is designed to tie in military, government, and non-governmental organization (NGO) efforts, but there is no overarching automated tool with which to coordinate operations. In terms of integrating operations at the operational level, some

warfighters recommended that more heavy construction assets be made organic to brigade combat teams (BCT) in S&R heavy missions. The warfighter stated that the engineer company in his area of operation (AO) was overwhelmed with the mission of providing battlespace operations (e.g., clearing obstacles and setting up barriers) as well as doing infrastructure projects (e.g., building roads and repairing buildings). Also, with limited earth-moving and concrete-mixing equipment, projects severely taxed available assets.

It comes as little surprise that non-line-of-sight *communications* in urban environments continue to present challenges to warfighters, and this was borne out by comments from NDU students as well as from more junior officers and non-commissioned officers from Ft. Hood. As highlighted in the previous report, the most "fail-safe" mode of communication warfighters relied on was cell phones. This continued to be the case for some time.[6] Cell phones were the means by which warfighters communicated among echelon, branches, coalition, and indigenous national elements. In addition, it continues to be the case that issues having to do with inability to communicate with another entity were overcome by cross-leveling equipment with that element. While a solution, this created shortages over time and was a temporary fix to an enduring problem. Commercial-off-the-shelf (COTS) systems were also used extensively (mostly Motorola systems), especially in convoy operations. However, these radios had limited range, were not always reliable, and did not provide secure communications.

Problems persist in terms of interoperability of incompatible radio systems (which speaks to the over-reliance on cell phones as a means of communication). In addition to cross-leveling systems, the use of liaison officers in host nation and coalition TOCs overcame some operational obstacles. Warfighters pointed out, however, that the numerous private security firms operating in their respective AOs often used communications packages that were incompatible, hindering coordination.

In terms of *translators and translations devices*, the issue of lacking assets seems to have been addressed. Warfighters stated that translators were readily available and accompanied almost every patrol they went on. However, the issue became less one of quantity than of quality and efficacy. Although ample translators were on hand, they were a command group asset (brigade and higher). Therefore, when requests for translators were put in, they were constantly rotated. No collaborative relationship was established between the translators and the warfighters. It was recommended that interpreters be more fully associated with patrolling units (through habitual relationships) to establish a rapport with the warfighters as well as with the citizens located in that particular AO. It goes without saying that sectarian sensitivities between Sunnis and Shias also played into translator effectiveness in AOs. For translation devices, the consensus was that these devices were good for "triage" and basic functions, but were not as effective for missions that required more complexity or nuance (or if a document was handwritten). This observation came from an officer whose unit's operations included the mission of document exploitation (DOCEX). Automated translation services also had ramifications for coalition operations. One officer explained that briefings and information material to be given to Iraqi forces had to be turned in one week in advance. Due to the extreme operational tempo (OPTEMPO) in their AO, information quickly became outdated. When automated devices were used in translating

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[6] Warfighters interviewed at a later date indicated that cell phone use had recently changed. Army policy now discourages the use of cell phones for operational use.

briefings, they found that these programs only did a “word for word” translation, which led to awkward or unintelligible briefings for Iraqi forces.

Addressing *limited situational awareness in urban environments*, survey respondents and interviewees pointed out that problems persist. Namely, the standard issue Precision Lightweight GPS Receiver (PLGR) continues to be a system that soldiers find cumbersome and not user-friendly. As stated in the SRO(I) report, warfighters have made extensive use of COTS systems (mostly Garmin) for navigational purposes. It seems that a shortfall in this regard—commercial map databases that lacked detail—has been addressed. Warfighters were satisfied with the level of detail in the Garmin system and made use of its ability to download updates in the field. However, presenting the positions of friendly forces in three dimensions continues to be a capability that is lacking. Coordination in this regard was made through voice communications.

For *intelligence (including sensors),* warfighters were generally satisfied with the systems available to them. Although most systems (e.g., UAVs or manned aircraft) were not organic to the unit, they could get access to imagery and other data after putting in a request for a particular grid coordinate or convoy route. However, company level operations were hindered in terms of sensor allocation when major events were occurring in other AOs. There was, it seems, a type of massing effect where all assets were directed at a specific “hot-spot.” This speaks to a need for some level of organic asset be made available at the battalion level (or company level contingent on costs) for ongoing operational requirements. Another drawback had to with bandwidth limitations in terms of passing data down to the tactical level. Warfighters stated that things took too much time to download.

Force protection was one of the most crucial issue areas of the SRO(I) report, and it continues to be a subject of overriding importance. On the whole, warfighters were satisfied with the measures taken to ensure their safety, however a variety of factors still presented obstacles. Counter-battery radar, for instance, was effective in *locating point of origin for mortar and sniper attacks*, but rules of engagement (ROEs) limitations precluded counter-fire. Further, for sniper attacks, warfighters stated that shooter detection equipment—although on hand—were not fielded in numbers adequate enough to make them operationally significant.

In terms of tools with which to quickly *check people, baggage, and vehicles* at traffic control points (TCPs), warfighters pointed out that a combination of detection systems were in use. Standoff detection continues to be the goal, however systems are still not reliable enough for this to take place. Warfighters with experience at TCPs explained that false positives registered with great frequency, which speaks to the difficulty of operating in complex urban environments like Baghdad.

Although ground forces have tools to adequately track and depict hostile forces, the *tracking and identification of civilians* continues to present challenges to warfighters operating in environments with large civilian populations. Warfighters explained that one problem had to do with there being too many databases—this being a function of the many military and government agencies operating in Baghdad. There seems to be no single, integrated identification database that can be accessed in real time over tactical communications. Most warfighters saw systems in use during their deployment as an ad-hoc collection of databases with various elements (e.g.,

CIA, FBI, DIA) as maintaining control and access.[7] In addition, systems like the Biometric Automated Toolset System (BATS) were mainly in the battalion TOC, and not accessible to lower echelon forces.

As division or brigade assets, warfighters stated that they could put in requests for **UAV** support (e.g., Raven and Shadow). Overall, respondents stated that they were pleased with the imaging these UAVs provided. However there were issues with UAV noise signatures compromising stealth, which echoed sentiments from other NDU interviews and surveys. Aerostats were also deployed with the Joint Land-Attack Cruise Missile Defense Elevated Netted Sensor System (JLENS), but their effectiveness was undercut by high winds during sandstorms as well as operator inexperience.

In terms of *information operations (IO),* the warfighters stated that the IO message of the day was disseminated each day to lower echelon units for further dissemination to local nationals. However, messages were generic and plastic in nature and—in their opinion—not very effective. One respondent explained that he cultivated relationships with local nationals by being completely honest about U.S. efforts (in that some endeavors were geared mostly for U.S. interests). By being up-front about his mission, he was able to deal with local leaders in a more open, direct way instead of hewing to official U.S. rhetoric that locals did not buy anyway. The warfighters also explained that they made use of local nationals for the production of posters and handbills for IO. In the end, U.S. IO efforts could often be undermined in one day by the insurgents. It seemed that U.S. forces were not nimble enough to counter the enemy's propaganda (it is important to note that the approval process for IO messages was cumbersome and slow).

In terms of *pre-deployment cultural training,* respondents stated that they were given briefings by expatriate Iraqi nationals that they found useful by way of giving a general overview. In addition, pre-deployment site surveys (PDSS) were conducted.

[7] Although not covered specifically in the first SRO report, it is important to note that warfighters commented that they could not easily pull information from these databases in a holistic manner. Specifically, they could not get useable products from fused information such as tribal map. This is being addressed through DOD's Human Terrain Mapping project.

Chapter 3. Use Case Analysis of S&R Capability Needs

Introduction

The questionnaires and warfighter interviews used in SRO(I) and in our update of that report in the previous chapter produced a nearly identical set of capability needs for S&R operations. This is a valuable finding, indicating a set of priorities for S&T investment. However, the capability needs are primarily an account of the personal views of warfighters, whose specialties and experiences may have been only a subset of all the specialties and experiences that should have been considered. Responses in questionnaires and interviews were weighted towards the most pressing concerns of the respondent. This is extremely useful, but focuses on current, personal knowledge rather than total capability requirements and can obscure comparatively minor (but still important) needs. Military medicine, chemical/biological protection, effects based operations, ground robotics, and Political, Military, Economic, Social, Infrastructure, and Information (PMESII) data, for instance, were not touched on in SRO(I) or Chapter 2. Additionally, there was little consideration for future needs or the implications of operating in other areas of the world. Thus, the authors thought it would be worthwhile to supplement these findings with a thought provoking exercise called the *use case analysis*.

A use case is another means for gathering requirements.[8] It is a narrative description of a sequence of activities a warfighter would undertake to accomplish a goal. For this study, the goal for each use case is to accomplish an S&R mission. The use case does not identify requirements, but rather implies them in the story it tells, leaving it up to an analyst to identify the requirements. The use case avoids identifying or describing specific technologies, but rather creates opportunities for analysts to identify capabilities that can be understood by a warfighter. The capability requirements we derived in this manner provided a valuable supplement to capability gaps established through questionnaires and interviews.

Generic cases allowed the authors to explore the full gamut of S&R operations and to define the required capabilities in the most general terms, without reference to whether a given need was currently being met. This effort to broaden the spectrum of considered capabilities is especially valuable given the long time it takes to produce useful technologies from S&T research; S&T efforts must encompass both current capability needs and those likely to emerge in the future.

As further support for this study, the findings from the use case analysis were discussed with warfighters at the U.S. Army Infantry Center, Fort Benning, GA. These veterans of S&R operations participated in a User Assessment/Validation Exercise (UA/VE) which provided a means for the study authors to develop a common understanding of capability needs with warfighters, to validate the selection of technologies for enabling particular capabilities, and to provide an opportunity for warfighters to "think out of the box" and identify capabilities which may not have been envisioned by the authors. A detailed discussion of the UA/VE and its output is in Chapter 4.

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[8] "Use case analysis" is a common term employed in Operations Research and Systems Analysis (ORSA) .

Three use cases used for identifying capability requirements and supporting the UA/VE were based on the following scenarios:

1. An IED explosion occurs in a large city and snipers are shooting at emergency responders. A reaction force (a U.S. infantry company augmented with a platoon made up of local nationals) is sent to secure the area and neutralize the snipers. Along the way the reaction force has to identify and deal with obstacles (crowded market, protestors, etc.). Once at the IED scene, the reaction force discovers that in addition to the snipers, local civilians may have been abducted and are being detained by insurgents. The reaction force receives additional orders to work with local police forces to verify the abduction, then locate and free the civilians. This will be identified in this report as the "Reaction to IED Attack" use case.
2. As part of a perimeter security operations mission, a U.S. battalion is required to establish a security zone that is much larger than its available manpower. Security is to be maintained using TCPs, dismounted patrols, unmanned air and ground systems, sensor networks, and other assets as appropriate. This will be identified in this report as the "Perimeter Security" use case.
3. A brigade moves into a section of a city and is totally responsible for all S&R operations in that area, which includes the reconstruction of an airfield in its area of responsibility. Focus of this use case is on battalion and above operations. This will be identified in this report as the "City Rebuild" use case.

One constraint was placed on the use case analysis effort. Due to the sensitivity of counter-IED technologies and vulnerabilities, counter-IED capability needs were not identified.

Use Case Development

The first step in the analysis was the development of the three *use cases*. The intent was to select three *use cases* which would stress different aspects of S&R operations with regard to stabilization versus reconstruction tasks, individual versus unit operations, level of operations (small unit through battalion), types of units, and consideration of PMESII factors.[9]

The story for each *use case* was developed using information from a number of sources. These sources included the subject matter expertise of the authors; information from warfighter interviews during the first S&R operations study; one author's (AAS) experience in designing and conducting experiments and demonstrations at Fort Benning, GA; U.S. Army doctrine and tactics manuals; and other open source material. The content of the available information skewed the development the initial scenarios toward Iraq and Afghanistan. The authors, however, wished to think beyond Iraq and Afghanistan. Therefore, the scenarios and the *use case* discussions focus on a generic "foreign country" and people rather than Iraq and Shiites and Sunnis.

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[9] Identified as political, military, economic, social, information, and infrastructure (PMESII) systems; Systems Perspective of the Operational Environment; FMI 5-0.1 The Operations Process; Headquarters, Department of the Army; March 2006

Additionally, the authors wanted the scenarios to reflect some of the unique aspects of S&R. Compared to normal combat operations, S&R operations have unique characteristics that stress Army warfighters and warfighting systems. Many of the differences can be attributed to a desire to reduce the loss of life and property destruction; promote a feeling of security (e.g., establishing security patrols and TCPs), while reducing the perception of U.S. martial law (e.g., reducing the visibility of tanks and armored fighting vehicles); promote day-to-day economic, social, and religious activities; and support large scale reconstruction efforts. As such, some of the unique characteristics of S&R operations are:

- ROEs are far more restrictive than in major combat operations so as to minimize "media opportunities" and prevent collateral damage. This severely constrains the use of large caliber munitions (and may, for instance, restrict the use of Active Protective Systems in the future).
- The warfighter is more a "dismounted policeman" than mounted or dismounted warrior. Within a city, tanks and armored fighting vehicles are often parked in motor pools and crews and squads are assigned to dismounted patrols.
- Maneuver operations are highly restricted since armored vehicles may damage streets, homes, automobiles, etc. Additionally, streets are often cluttered with day-to-day activities that should not be interrupted with military operations. Finally, units are assigned to static bases.
- There is much more background clutter in the form of radio transmissions, lights, pedestrians, civilian automobiles, and other interferences that degrade the performance of military communications, sensors, and human sensing. For example, numerous lights at night interfere with the performance of night vision goggles.
- Reconstruction efforts span large areas and cross many maneuver unit boundaries
- Long haul logistics are more the norm
- The air space is very complex, due to the much greater use of manned and unmanned military and civilian aircraft, as well as the occasional use of non-line-of-sight munitions. It is very difficult to deconflict the airspace, which often deters the use of unmanned aerial systems by battalion and below forces.
- The probability of warfighters interacting with civilians is high so there is a much greater requirement for our warfighters to understand the local populace in terms of language and culture.
- There is a much greater concern for coordinating diplomatic, information operations, military, and economic (DIME) actions and their effects on PMESII systems.

This last bullet point deserves elaboration. Combat operations focus principally on a limited, concrete set of effects, such as the number of targets engaged. In S&R operations a longer list of important effects rise to the fore; for example, actions such as restoring electricity, water, sewage disposal, and garbage collection will most likely have a greater impact on the attitude and cooperation of the populace than the neutralization of the insurgents. Additionally, PMESII systems must be considered at all levels of operations, from small unit stabilization missions through theater operations. Obviously, senior commanders are concerned with theater-wide impact of DIME activities on PMESII systems. Not so obvious is the consideration a small unit must give to PMESII systems when planning an operation. For example, if a unit needs to move a group of supply trucks with construction equipment from point A to point B in a foreign country, it should consider in its planning:

- The common military considerations like C2, frequencies, security, etc. (*military* consideration)
- Augmenting its military drivers with local national truck drivers (*economic* consideration)
- Augmenting its convoy security with local security forces (*political* and *military* consideration)
- Avoiding neighborhoods of a particular sect or religion if the local national truck drivers in the convoy are at odds with the people in these neighborhoods (*social* consideration)
- Avoid emphasizing a military presence near political or religious sites (*political* and *social* consideration)
- Avoiding market areas during times when markets are crowded and streets are clogged. This would disrupt the marketplace as well as slow down the convoy (*social, economic,* and *military* consideration)
- Avoiding hotel, club, or theater district areas during the latter part of the day (*social, economic,* and *military* consideration)
- Avoiding disturbing families relaxing in parks, trying to get to an activity in a stadium, or other leisure activities (*social* consideration)
- Avoiding routes where the size and weight of the trucks may damage roads, bridges, power lines, etc. (*infrastructure* consideration)

While future S&R operations could be conducted in many different environments and will vary in the relative demands they put on certain capabilities, it will remain important to be able to operate effectively in urban areas. Towns and cities are not only population centers, but centers of commerce and seats of national and local governments. As such, they will need the most immediate attention in terms of providing security, reconstituting basic services, building local capacity, and conducting reconstruction operations. Yet U.S. commanders have long chosen to avoid operating in urban areas whenever possible, and for good reason. The adversary has far better knowledge of the complex local environment and, unlike U.S. forces, may have no qualms about endangering noncombatants. Many of our strategic and operational command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) systems are less effective in the urban environment than in open terrain. Dense, complex structures and civilian populations make it harder to discern the enemy.[10] With both their enduring importance and our relative capability shortfalls in mind, we have chosen to focus the use cases on urban operations.

The use case analysis was also designed to illuminate emerging tactical and technical capability needs that apply when stabilization operations transition to force on force conflict, especially in urban environments. The U.S. military has focused significant effort on improving full spectrum operations in urban environments and is developing appropriate new tactics, techniques, and procedures (TTPs). Figure 1 addresses some of these changes. No longer will U.S. forces seek to surround an urban center and clear it in a linear fashion. Also, U.S. military forces are increasingly focused on minimizing collateral damage. Thus, TTPs will focus on operations that isolate adversarial nodes in a city, provide precision attacks on those nodes, and support the non-

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linear movement of forces through cities. These TTPs will require significant improvements in situational awareness, precision strike capabilities, and battle command.

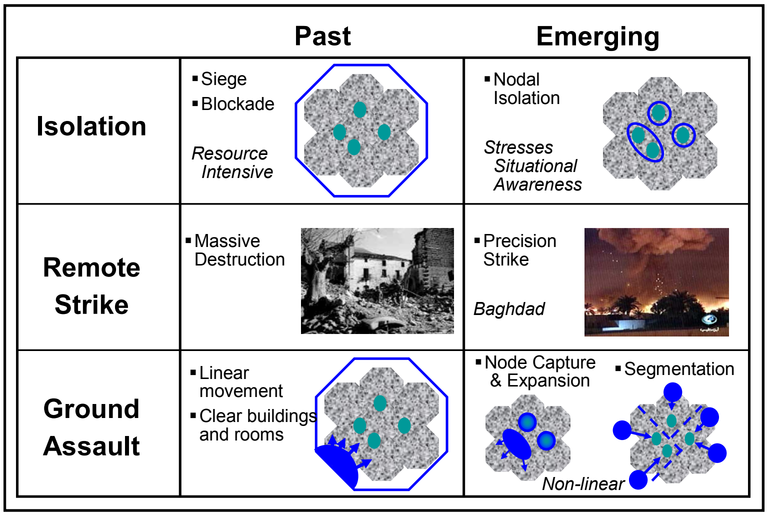

Figure 1. New TTPs for joint urban operations.

Battle command of military forces has become increasingly difficult. Recent conflicts have called for rapid, dispersed operations with joint and coalition forces. The problem is compounded in urban environments where units can become isolated. To address this problem, technologies are being developed to support the commander's ability to think jointly and execute in four dimensions — the "x" (length) and "y" (width) dimensions of the horizontal battlespace most accustomed to our land forces, especially in open terrain; the "z" (height) battlespace dimension, which is defined in urban settings by tall buildings and underground facilities; and the "time" dimension of actions that have occurred or will occur. A critical part of the "z" dimension is the important contribution manned and unmanned aerial systems can make to urban operations. Networked sensor systems, see-through-wall sensors, blue force tracking systems, and decision aids are being developed to overcome difficulties with partial or missing information, time constraints, poor battlespace visualization,[11] and challenges with synchronization of assets and operations. To augment their forces and keep warfighters out of harm's way, commanders will control a mix of unmanned and autonomous systems, including sensor systems as well as robotic systems (see Figure 2).

[11] Battlespace visualization includes "seeing" U.S. & coalition forces (including military and police), adversaries, and non-combatants (U.S. and Allied personnel, as well as local civilians).

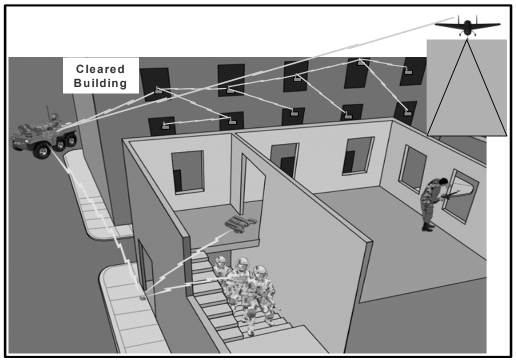

Figure 2. New TTPs and capabilities for urban operations.

To limit noncombatant casualties and collateral damage, commanders will be provided greatly improved battlefield awareness, hit avoidance, and more focused combat power. Units will be able to operate independently and out of sight of other units because of improvements in communications and warfighter tracking systems. Human performance technologies will greatly enhance individual and organizational performance. Cultural awareness and language translation systems could allow commanders to better understand the diversity of cultures and languages faced by today's warfighter. Battle Command decision aid tools will consider DIME actions and their effects on PMESII systems.

The Use Cases

Each use case is based on the same **General Situation**:

> The United States has recently completed combat operations in a foreign country and has transitioned to stabilization and reconstruction operations. Formation of a new government is underway, as well as the development of its military and police forces. U.S. stabilization forces have been positioned throughout the country in static, battalion-size bases and have been using peacekeeping, cooperative activities, and coercive actions to maintain order in cities and provide security for U.S.-sponsored reconstruction operations in their assigned sectors. U.S. funded reconstruction operations are primarily focused on repairing or upgrading the utilities and transportation infrastructure. All stabilization missions are coordinated and conducted with the participation of the local national military and police forces, as well as non-DOD U.S. entities.
>
> Insurgent activities continue to plague U.S. and local government efforts to rebuild the country. Current intelligence indicates there are three major insurgent factions:
>
> 1. Non-state actor terrorist organizations comprised of a combination of local nationals and foreign insurgents who have infiltrated the country in question.
> 2. Ethnic/religious militant groups. These ethnic/religious factions are closely related in terms of ancestry and beliefs. However, they believe that a few sharp differences exist that justify violence toward each other. Local national police and military forces are often established with a predominance of one ethnic/religious group or another.

3. Criminal groups. These groups attempt to use violence to ensure money is provided to them in the form of contracts, grants, management fees, and even illegal payments.

All three insurgent factions use a combination of IEDs, snipers, and small paramilitary forces to promote violence.

The specific situation and associated series of actions are distinct for each use case. The three use cases will now be briefly discussed below.

Use Case 1: Reaction to IED Attack

Specific Situation. An IED has exploded in a market place. Local emergency responders have arrived; but triage, medical, utility restoration, and clean-up efforts are being hindered by at least two snipers. A U.S. reaction force (an infantry company, about 160 personnel), augmented with a local national infantry platoon (about 40 personnel) and U.S. medical personnel, is tasked to move to the scene to help restore order and assist with medical needs. The infantry company commander and platoon leaders are to make contact with the local police force upon arrival and coordinate efforts with them. The attack occurred mid-afternoon when the market place is extremely crowded with pedestrians, automobiles, and street vendors. The market place has one- to five-story commercial stores on either side of the street and is frequented primarily by one of the warring religious groups. This may be an issue since the augmented infantry platoon is representative of the opposing religious group. Additionally, there have been reports of civilians gathering in large groups in nearby neighborhoods to protest the attack. Historically, these gatherings become violent when they come in contact with opposing religious groups. Soon after arriving at the scene, the company commander receives unconfirmed reports from locals that an additional complication may have arisen. It has been reported that a local official traveled to the scene to view the area, and while there, he and his driver were abducted by the insurgents. It is suspected he and his driver are being kept against their will somewhere in a block of residential housing adjacent to the scene of the IED attack. The local neighborhood buildings surrounding the market place are comprised mostly of one to two story residential homes closely packed together. After reporting this information to the Battalion Commander, the company commander is ordered to work with local police to resolve this new problem. Efforts are prioritized in the following order: locate and neutralize the snipers; secure and support humanitarian assistance at the IED incident; verify the reported abduction; if the abduction occurred, find and assist local forces in recovering the official and his driver. Some of these actions can occur simultaneously. Note that this is the Three Block War[12] scenario.

Series of Actions: To accomplish this mission the augmented U.S. infantry company must accomplish the following activities:

- **Plan operations**. Static (prior to movement) as well as dynamic (en-route) planning and re-planning. Assessment of the mission, enemy, terrain, troops, and time available (METT-T). Integration of available military assets, non-U.S. assets, unmanned systems

[12] The Three Block War was conceived by General Charles Krulak to describe how the full spectrum of war could be faced simultaneously by warfighters in lower echelon units. In three adjacent city blocks, soldiers may be required to conduct full scale military action, peacekeeping operations, and humanitarian relief.

(robots and sensors), latest terrain/feature data, and PMESII systems. Battlespace awareness, course-of-action analysis, mission selection, and mission rehearsal.

- **Move to IED scene.** While en-route, protestors begin to gather in a road that is part of the planned route for the reaction force. The situation at the IED site changes—insurgents abduct a local official and his driver. Abduction is seen by locals, but because of the confusion with dealing with casualties, fires, and building damage, this information is not reported to proper officials.
- **Secure the area.** The reaction force arrives on the scene. Perimeter security is established using a combination of vehicles, dismounted personnel, sensors, and unmanned ground and air systems. Ad-hoc traffic control points are established. Civilians' identities are checked against databases.
- **Locate, identify, and neutralize the snipers.** Using a combination of human intelligence (HUMINT), signal intelligence (SIGINT), imagery intelligence (IMINT), urban terrain analysis systems, and historical data, likely and known sniper locations are identified. Sniper location systems are used to locate the sniper when shots are fired on the reaction force. Once identified, non-linear tactics and networked weapons systems are used to neutralize the sniper. While the reaction force accomplishing this task, a second sniper opens fire and the reaction team adjusts to neutralize this additional sniper.
- **Assist with medical needs.** While military actions are taking place against the snipers, assistance is being provided at the scene of the IED attack. Military personnel assist local emergency responders with their duties. Because of the devastation, additional U.S. emergency responders are brought to the area. The local commander must be able to coordinate humanitarian assistance being provided by his personnel and the newly arrived U.S. personnel along with the local emergency responders, and doing this while neutralizing the snipers and setting up perimeter security. Additionally, in these situations, U.S. personnel have to consider personal medical safety, since in addition to the dangers of military attacks, there may be situations where local civilians may be afflicted with a contagious disease.
- **Verify, locate, and assist with freeing the detained civilians.** Once the sniper situation is under control, the company commander has to respond to a new order to verify, locate, and assist with freeing the detained local official and his driver. This activity within this use case scenario repeats many of the activities mentioned above—plan the operation, move to the area of operations, secure the area, and then assist with the detained civilians. The major difference from the "neutralize the sniper" activity is that here the local security forces lead and execute the effort with U.S. military forces in a supporting role and subordinate to the C2 of the local security force leader, who is a policeman. It is hoped that military actions will be kept to a minimum, but if needed, the military commander will minimize collateral damage by using actionable information, such as knowing the building and room holding the detained civilians and their abductors as well as their location and orientation in the room.
- **Treat/evacuate casualties.** Medical attention is provided to U.S. casualties as they occurred during the mission. Triage and life-saving actions were taken, as needed. Casualties needing evacuation are moved back to aid stations as rapidly as possible. Assessment of air evacuation must take into account urban structures which may be too high and close together for helicopters to get near the company's area of operation.

- **Consolidate forces.** After operations are completed and the situation is fully under control by local police and medical personnel, the company commander is ordered to consolidate his forces. This requires rapid assessment of the location and activities of all personnel and equipment (e.g., unmanned systems) involved with humanitarian assistance, perimeter security, sniper neutralization, and freeing the detained civilians. All assets (e.g., sensors and unmanned systems) must be retrieved.
- **Depart the area.** In planning an evacuation route the company commander must work closely with battalion headquarters to assess routes in the same fashion as the initial planning and movement tasks above.

Use Case 2: Perimeter Security

Specific Situation. A U.S. battalion has moved into a section of a large city and must secure a very large area as a “Green Zone” for the newly established local government officials, a higher echelon U.S. headquarters, U.S. reconstruction personnel, journalists, and various other personnel and organizations.

Part of the security effort is to establish six TCPs. At these TCPs, explosive detection is critical because of the requirement to have local workers and reconstruction and resupply vehicles pass into the green zone. Each day, the U.S. battalion must process approximately 10,000 pedestrians and 3,500 vehicles through its six TCPs. The longer the explosive detection process, the more inconvenient it is for the workers and the greater the impact on meeting reconstruction goals each day. There is pressure on a daily basis to move traffic through the TCPs faster. Each day the military personnel must balance security with convenience.

In addition to the TCPs, a perimeter security zone must be established using a combination of dismounted patrols, unmanned air and ground systems, sensor networks, and other assets as appropriate. All activities are being coordinated by the battalion staff within the Green Zone, with its battalion headquarters operating within a combination of buildings and the battalion’s headquarters vehicles. Local electrical power is sporadic and does not support the headquarters in a consistent manner.

Dismounted patrols are complicated, as this U.S. battalion is a mechanized unit and most of its armored vehicles are parked in a motor pool within the Green Zone. Occasionally, a tank or infantry fighting vehicle is brought out to augment a TCP or dismounted patrol.

Series of Actions: To conduct this mission the battalion must accomplish the following activities:

- **Set up battalion headquarters.** Consider moving command, control, communications, and computer equipment from vehicles to buildings. Consider power needs, positioning of antennas, need for repeater stations, etc. As perimeter security is set up with persistent surveillance using TCPs, patrols, unmanned systems, and sensor networks, a significant amount of information will begin to flow into the battalion headquarters.
- **Establish TCPs.** TCPs are needed which can handle the flow of people and vehicles, yet have capability to identify dangerous situations (e.g., suicide bomber) at a reasonable

distance and in reasonable time. If the dangerous situation is not identified in time, TCP personnel must be protected from adverse events (explosions, gun fire, etc.).

- **Set up and implement dismounted patrols.** Armored vehicles are parked in large motor pools and crews must now use organic equipment to conduct dismounted patrols.
- **Utilize unmanned air and ground systems.** Unmanned air and ground systems must support TCPs, patrols, and observation points.
- **Set up sensor networks.** Sensors provide data from combinations of non-imaging and imaging sensors to automated information systems that alert users to abnormal or suspicious activity.

Use Case 3: City Rebuild

Specific Situation. A U.S. brigade with an attached combat engineer company has moved into a city immediately after full combat operations and is totally responsible for all S&R operations in that area, which includes the reconstruction of an airfield in its area of responsibility. In addition to the reestablishment of basic utilities (water, electricity, sewage removal, garbage removal, etc.), there is a need to reestablish services such as (political, law enforcement, medical, etc.).

All basic utilities except for garbage removal are provided from outside the city. Most water, power, and sewage lines are destroyed or non-existent. A U.S. contractor is responsible for rebuilding the airfield. Most supplies, especially for the airfield, are being transported from other parts of the country. For example, gravel for the airfield runway has been subcontracted by the major U.S. contractor to a local commercial trucking company and is being hauled from a quarry about 100 miles away. Since the airfield reconstruction activities have started, insurgents have been attacking the airfield, the truck convoys, the quarry, and family members of the truckers and quarry workers. These attacks have been in the form of shootings, beatings, and in one case a decapitation. U.S. convoys for other supplies have been attacked with IEDs. It appears that the airfield-related attacks are from local organized crime, while the attacks on U.S. convoys are being conducted by non-state actor terrorist groups.

Note: Focus of this use case is on Battalion and above operations.

Series of Actions: To accomplish this mission the brigade must accomplish the following activities:

- **Coordinate reconstruction schedules with stabilization missions.** A COP is established so that reconstruction activities are visualized in an integrated picture with stabilization missions. Maneuver units can plan daily stabilization missions as well as task units for providing security for reconstruction activities. The reconstruction personnel can better schedule the arrival of supplies and breadth of activities based on its view of the availability of security forces.
- **Reestablish essential utilities (water, electricity, sewage removal, garbage removal, etc.).** Commander must have a consistent view of the availability of essential utilities. The capabilities of main facilities (power plants, water stations, etc.) must be seen along with views of distribution systems and demands as utilities are reestablished. Soon after a major conflict, and until appropriate support arrives on station, the ability to reestablish essential utilities rests in the hands of the military units in control of an area.

- **Reestablish essential services (political, law enforcement, medical, etc.).** Immediately after a conflict, the military unit in control of an area must be able to quickly identify and communicate with local officials to determine how best to restore essential services. In some cases, personnel will need to be quickly trained.
- **Assist with clean-up of rubble and rebuild of local buildings.** Military engineer equipment will be needed to assist with immediate reconstruction needs.
- **Coordinate with local authorities.** Local authorities and military leaders work as a team to restore the services and utilities. Language and cultural barriers need to be overcome. The issue of organized crime must be resolved.
- **Assist with the construction of the airport by providing security for the airport, trucking, and quarry operations.** A construction project of this magnitude mandates the use of a U.S. contractor. Maneuver forces must coordinate closely with the contractor to provide security of all phases of the effort.
- **Interact with contractors and non-government organizations.** The influx of contractors and non-government organizations increases rapidly after the major conflict is over and focus is on S&R operations. Communications are hampered by lack of interoperable systems and multi-level security issues.

Results of the Use Case Analysis

The use case analysis effort identified a set of capability needs for S&R operations. Some of these capabilities were clearly suggested by the scenarios. Others were generated by second and third order considerations. A detailed list of the capability needs is in Appendix C, Detailed Results of the Use Case Analysis. Below are highlights from the detailed list of capability needs.

Battle Command

1. Ability to synchronize combat, humanitarian assistance, and S&R operations, potentially simultaneously
2. The integration and visualization of reconstruction operations as part of the COP for daily stabilization operations
3. Interoperable communications among U.S. military and non-military organizations, foreign military and non-military organizations, and others
4. Ability to visualize 3-dimensional (3D) operations with PMESII overlays and well conceived rules of engagement
5. Ability to track entities or activities that are normally not tracked or are normally tracked in small numbers—e.g., scaling up to track thousands of civilians who are conducting day-to-day activities
6. The deconfliction of air space for use of UAVs by battalion and below force elements
7. The ability to command, control, and communicate with units operating in environments where today’s radios and GPS systems work poorly

Small Unit Operations

1. Persistent blue force tracking for all personnel, including visualizing 3D location of all forces in complex environments above and below ground
2. Presentation of 3D representation of area of interest, including PMESII data

3. Multiband beyond line-of-sight (BLOS) radio capable of secure voice and broadband data links
4. Hands-free use of information systems during assault

Battlespace Awareness

1. Total asset awareness—location and identification of U.S. forces, non-U.S. forces, local police forces, non-DOD assets, etc. Note: in S&RO the availability of these assets changes daily, unlike in combat operations where a commander knows what assets are tasked to him in direct support
2. Persistent tracking of blue, red, and white entities in an AO
3. Visualization of reconstruction activities in an AO
   a. For example, schedule of reconstruction material convoys near or through areas of operation
4. Ability to rapidly gather, fuse, and display 3D terrain and feature data
5. Visualization of likely enemy locations (including for snipers and IEDs)

Intelligence, Reconnaissance, and Surveillance

1. Persistent surveillance systems
2. See-through-wall sensing
3. Access to military and non-military intelligence information from both U.S. and non-U.S. sources
4. Knowledge of and location of intelligence gathering systems in the area (ground based sensors, UAVs, HUMINT, satellite imagery, etc.)
5. Availability of launching ISR systems in real time—self-configuring sensor networks, unmanned systems, etc.—or tasking national assets
6. Identify and track insurgents, vehicles, and weapons (including IEDs)
7. Historical data/trends of insurgent activity in the area, including ability to identify why an activity (e.g., abduction) may have occurred
8. Impact of culture on enemy actions
9. Information on controls for electric power and other utilities to the target area

Force Application

1. Tools/technologies that may be able to "free up" resources to support battalion operations (e.g., augment some scheduled manned missions with unmanned systems)
2. Automated tools for identifying protected, covered, and concealed movement
3. 3D entry into and extraction from buildings (including ability to enter buildings other than through 1st floor doors and windows)

Force Protection

1. Lightweight, full body, personal protection systems
2. Advanced vehicle/personnel protection from blast
3. Mobile TCPs
4. Mobile screening systems
5. Ability to block all traffic (above and below ground) and communications in and around an AO

Unmanned Systems

1. Use of robotics at traffic control points
2. Use of robotics at observation points
3. Interaction of robots with local populace—e.g., implementation of rules of engagement
4. Use of robotic systems in reconstruction and logistics activities

Non-Lethal Capabilities

1. Hands-free use of non-lethal weapons
2. Rapid transition from non-lethal to lethal weapons
3. Focused non-lethal capabilities that do not harm/interfere with blue force systems

Information Operations

1. Tools that block insurgents from distributing their propaganda (e.g. cell phone jamming, jamming of video recorders)
2. Rapid access to array of reliable media, especially local but also global
3. Tools for mapping cultural data (location of religious sects, identification of religious/historical buildings, etc.)

Logistics

1. Ability to coordinate movement and support from reaction forces while traveling through numerous unit sectors
2. Rapid integration of host nation assets

Combat Medicine

1. Enhanced capabilities for treating blast and burn victims
2. Ability to rapidly identify and diagnose brain trauma
3. Advanced capabilities for reducing bleeding

Mitigation of Collateral Damage

1. Non-lethal weapons
2. Mobile triage systems
3. Precision munitions
4. Integration of reconstruction assets

Reconstruction

1. Making area safe (e.g., EOD) for returning civilians
2. Rapid repair of damaged structures and utilities
3. Ability to train and utilize local assets

Training

1. Tools for rapidly training personnel for S&R operations (e.g., rebuilding a town)
2. Tools for rapidly educating personnel on cultural diversity issues
3. Tools for maintaining combat efficiency while conducting long-duration S&R operations

Chapter 4. Warfighter Assessment of Use Case Analysis

Just as the authors identified shortcomings in the robustness of using surveys and interviews of a limited sample size of respondents who did not represent the full spectrum of expertise and experience in S&R operations, so too did the authors recognize that the use case analysis may have some inherent shortcomings. Recognizing that the list of capability needs identified in Chapter 3 is too long (as fully listed in Appendix C), not prioritized, and most importantly, based on a use case analysis conducted by inexperienced authors rather than experienced veterans of S&R operations, the authors decided to conduct a UA/VE to review the findings in Chapter 3. The UA/VE was coordinated with a senior DOD engineering psychologist assigned to the U.S. Army Research Laboratory (ARL) Human Research and Engineering Directorate (HRED) Fort Benning Field Element and was conducted at the U.S. Army Infantry Center in Fort Benning, GA, specifically at the U.S. Army Officer Candidate School.

The UA/VE was conducted with 22 Army officers, officer candidates[13], and non-commissioned officers (NCOs), representing the infantry, armor, artillery, signal corps, transportation, and medical branches. About half were officer candidates and senior NCOs, and the other half were captains and majors. All of them had recent in-country experience in S&R operations, the great majority in Iraq, but also in Afghanistan, Bosnia, and Africa. We interviewed them in groups of four to twelve over two days.

The participants were grouped as follows:

- Group 1: Officer Candidates and NCOs who participated in small unit S&R operations. Most of the members of this group served in fire team, squad leader, and platoon sergeant positions. A few served in non-combat arms positions.
- Group 2: Captains and a major who served as platoon leaders or other company level positions. One officer served as an artillery battery commander.
- Group 3: Captains and a major who served on battalion or brigade staffs. The discussion for this group focused primarily on the Battle Command capability needs.

We outlined the use cases for each group and then went through a lengthy, anonymous questionnaire designed to collect their opinions on the kinds of capabilities needed to cope with the use case scenarios. The participants were encouraged to think creatively about the capability gaps and not to be bound by potential technical barriers to meeting a particular need. We both collected their written comments and took notes on the discussion stimulated by the use cases and the list of capability needs.[14]

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[13] These officer candidates were members of the Officer Candidate School (OCS) at Fort Benning, GA. Prior to volunteering for OCS, they served as non-commissioned officers (mostly Sergeant, Staff Sergeant, and Sergeant First Class) in S&R operations.

[14] Please note that, despite the fact that one of the use cases focused on an IED attack, our discussion with the warfighters did not dwell on IED defeat capabilities. Though such capabilities are perhaps the most pressing need the Army faces today, we did not want to discuss material unsuitable for an unclassified report. Further, this capability need is well-recognized and is being aggressively pursued by, among others, the Joint IED Defeat Office.

Although the discussions were detailed, candid, and illuminating, this warfighter analysis is of qualitative rather than quantitative value. No statistical significance can be attributed to the data we collected, and the reader must be mindful that even the qualitative information we collected came from a small number of warfighters whose opinions on capability needs for S&R were heavily influenced by the current conflict in Iraq. The fact that we received significantly more feedback on some topics than on others reflects not just the relative importance attributed to a given area by the participants but also group composition and the ebb and flow of the interview session. For instance, there was not much discussion of capabilities for reconstruction operations. While reconstruction-related capabilities are clearly important for S&R operations, none of the warfighters with whom we spoke were civil affairs personnel and very few served at an echelon that would have much use for, for instance, planning tools for reconstruction operations.[15]

The warfighter assessment at Fort Benning both supported the findings of our first report and also countered the authors' tendency to assume that warfighters would fully support the need for most or all of the capabilities identified in Chapter 3 and fully listed in Appendix C. The warfighters' insights were valuable on four counts: they helped group and prioritize the numerous capability needs identified in use case analyses, they elaborated on current capability shortfalls, they detailed desired capabilities, and they warned of particular pitfalls associated with introducing new technologies. We present the highlights of the questionnaires and discussion below, focusing on the two main capability areas that received the most attention—C4 and ISR. The chapter concludes with an inclusive discussion of other capability areas and some comments on broad themes in the warfighter assessment.

Command, Control, Communications, and Computers (C4)

Command, control, communications, and computers (C4) received a great deal of attention during the UA/VE. Interoperable and portable equipment seemed to be the biggest communications capability needs, and technologies to improve battlespace awareness would also be very useful.

Put broadly, the warfighters expressed that more communications capability was always a good thing. Warfighters were especially concerned about communicating with personnel from other units and other Services on the ground at the small unit level. Often, it was difficult to know what frequencies other units and organizations were using. Army and Marine Corps units use some incompatible equipment. Even in those cases when Army and Marine Corps units have compatible radio equipment, they may use different COMSEC practices. Nor are issues limited to voice communications. The Army, which equips its warfighters with night vision equipment, makes frequent use of infrared (IR) flashes to signal during nighttime operations. The participants reported that night vision gear was significantly less available in Marine Corps units.

[15] Timing may have had something to do with limited reconstruction experience we found in our groups of interviewees. Broadly speaking, the military has had increasingly less civil management and reconstruction responsibilities since the initial invasions of Afghanistan and Iraq, with more duties devolved to local authorities and contractors. Most of the warfighters we spoke to in April 2007 were drawing on recent deployments; their experiences might have been different if they were in Afghanistan in 2001-2002 or Iraq in 2003-2004.

Army-to-Air Force communication also needed improvement. Army personnel at the brigade level in Iraq initially used an internet-based chat system to communicate with Air Force pilots. This helped coordinate operations, but the method was unauthorized and was later forbidden. Such a text-based system would be useful, though the warfighters indicated that information passed to battalion and below would need to be filtered for relevancy.

Joint support operations could also benefit from improved inter-unit and intra-Service communication. For example, and Army field hospital supporting multi-Service units in Iraq was unable to receive notice of incoming Marine Corps casualties, leaving staff less prepared than they were for comparable Army casualties.

These problems of communicating at company level and below dictate that movement by Army units and units from other Services through AOs other than their own must be coordinated well in advance. This coordination sometimes breaks down, even in cases as straightforward as notifying units that a supply convoy will be passing through their AO. Further, many operations are undertaken in response to a crisis and cannot be coordinated in advance.

The warfighters with whom we spoke were less concerned about communications with contractors, NGOs, and host nation forces. Though it was even harder to communicate with such entities, the need to do so was less pressing than the need to communicate with other U.S. military personnel.

Some communications problems could be alleviated by making vehicle-borne capabilities soldier-portable. The AN/PRC-148 Multiband Inter/Intra Team Radio (MBITR), while not a replacement for vehicle communications suites, received fairly positive reviews, and warfighters wished that more were available. More broadly, though, communications equipment that makes it straightforward to talk to other U.S. military units and, after taking communications security (COMSEC) into account, non-U.S. military entities in a given AO is a keenly-felt technology need. In the short term, warfighters suggested establishing an open radio frequency that all units could monitor. After making initial contact through that frequency, units could coordinate a shift to another, more secure channel to continue communication. Alternatively, communications gear could be rigged to flash the appropriate frequency to other units.

Warfighters also identified the portability of C4 equipment as a key issue. Decreasing the weight carried by troops in the field is always an important concern, but their needs go beyond light-weight radios. Currently, unit commanders are tied to their vehicles for C2 in the field. A company commander's High Mobility Multipurpose Wheeled Vehicle (HMMWV), for instance, has three to four Single Channel Ground and Airborne Radio Systems (SINCGARS), FBCB2, a high frequency radio, and several other devices. These are bolted to the vehicle, and draw power from it. Warfighters indicated that for some operations it would be very useful if such equipment were modular, and could be moved quickly (and powered locally) to establish a command post in a building.

Battlespace awareness was another issue of significant concern for warfighters. They expressed a strong desire for the capability to have access to relevant, dynamic PMESII data. They were also interested in improved capabilities to track Blue, Red, and White forces on the battlefield. This

and other information, though, could become overwhelming. Warfighters suggested that personnel at platoon level, and perhaps also at higher echelons, be dedicated to "information overwatch."[16]

Warfighters want information management tools that aggregate and present relevant PMESII data, as described in Chapter 3. Currently, units undertake individual PMESII collection efforts. The data may or may not be readily accessible, may or may not be linked to a map, and is usually unclear whether it is up-to-date. Further, data is not standardized, so it is not readily passed from unit to adjoining unit or from unit to replacement unit. Any technology solution should be standardized for use across the services. It should have easy-to-use tools that both allow the user to sort information by type and age and allow filtering for echelon and mission relevance.

Warfighters expressed an interest in enhanced Blue, Red, and White tracking capability. They were especially attentive to the granularity of the desired information. Even if total awareness was possible, too much information, especially at small unit levels, could be a serious hindrance. They desired Blue tracking capability down to squad level, but no further. Total Red awareness would be ideal, though they were skeptical that this could be achieved, especially in an environment like Iraq. They only wanted general information on White movements.

Timeliness was also vital. If the data picture was not dynamic, it was of little use. Warfighters indicated that either because of circumstance or the sheer volume of information, it simply was not feasible to expect personnel to key the needed data into digital systems in a timely fashion. One suggested solution to this issue was to capitalize on voice recognition software. Information on Blue, Red, and White locations is currently the subject of substantial radio traffic during the course of operations. This radio traffic often makes use of standardized terminology. A computer program could collect audio information pertinent to tracking Blue, Red, and White and input that information directly on a common map, updating as necessary. Several sources of error can be imagined. The utility of tracking data diminishes sharply if it is not reliable, as well as if it is not timely; the two imperatives would have to be weighed against each other.

The possibility of dynamic tracking of the civilian population excited several of the warfighters. They pointed out that in Iraq, civilians often know of an impending attack on U.S. and friendly forces. Persistent surveillance and instant pattern analysis could help U.S. forces capitalize on that knowledge. For instance, if civilian foot traffic on a given street declines radically on a given day, it could indicate that an IED has been emplaced nearby. Tracking and automated analysis of general movements could alert U.S. forces to a possible threat.

Warfighters also saw the need for improved information collection on individual civilians, suspected hostiles, and known hostiles. Units in Iraq today frequently maintain their own databases on persons of interest in their AOs. This information is not readily accessible during

[16] Information overwatch is a term developed by one of the authors. Typically, overwatch is the state of one small unit or military vehicle supporting another unit, while they are executing fire and maneuver tactics. An *overwatching*, or *supporting* unit takes a position where it can observe the terrain ahead of the maneuvering unit, especially likely enemy positions, and provides covering fires. In this case, information overwatch is when an individual (commander, platoon leader, squad leader, fire team leader, fellow Warfighter) or unit can remotely overwatch the actions of individuals or small units (squad through company), and support individual Warfighters or small units with relevant information (past, present, or future).

the course of a mission or at checkpoints, is rarely accessible to neighboring units, and not certain to be used by replacement units. A portable device with face recognition, fingerprint recognition, or eyescan (retina) recognition capability would, if backed with access to a country-wide database, be extremely helpful. Such biometric data would alert warfighters as to when they had a person of interest, limiting cases of mistaken identity and improving the effectiveness of checkpoints. Such a device, though, would have to work quickly—warfighters could not detain civilians for an extended period while waiting for information. A country-wide database would ensure that valuable data was not lost when units rotated and would help to prevent hostile forces from exploiting the seams between U.S. AOs.

Improvements in all these capability areas—interoperable, portable communications, blue, red, and white tracking—would solve many problems, but they would also create some. Warfighters indicated that they were concerned about being overburdened with information, leaving them unable to quickly execute their primary missions while taking full advantage of the data available to them. One solution they suggested was creating an "information overwatch" role at the platoon level. A designated warfighter's primary responsibility during a mission would be to monitor communications and other data, make assessments, and provide that information as needed to the right warfighter at the right time. A similar function could also be performed by a warfighter at the company or battalion level, with the latter providing a closer linkage between the Battalion Intelligence Officer (S2) and units on stabilization missions.

Intelligence, Surveillance, and Reconnaissance (ISR)

Two ISR capability areas stood out for warfighters: unmanned systems and persistent sensors.

Warfighters saw a variety of capability shortfalls associated with current unmanned systems. UAVs, even small, electric UAVs like Raven, are quickly seen and heard by hostile forces, which sharply decreases their value as an ISR asset. Warfighters did not want UAVs on some missions because they would warn the intended target, and reported being unhappy that more senior officers would insist on surveiling a target area with a UAV before sending in troops.

Conversely, when warfighters did want UAVs, they were difficult to obtain in a timely fashion. They were generally brigade and above assets, and because of air space deconfliction issues their use had to be scheduled in advance. Getting a UAV could take 48 to 72 hours prior notice. Not all units experienced this difficulty to the same degree. Cavalry regiments, for instance, had organic UAVs and further had better access to manned rotorcraft for ISR support. Further, warfighters also indicated that UAVs were a significant drain on manpower. A UAV required two operators. It also required that a platoon be kept on call to recover it in case it crashed.

There are several areas, then, in which UAV capabilities could be improved. Low-signature UAVs would be extremely useful, though such vehicles would have to get extremely quiet and extremely low-visibility to avoid detection by hostiles who are acutely aware of the threat UAVs pose. Alternatively, omni-present UAVs would avoid tipping hostile forces that their particular activities were of interest to U.S. forces. Low-cost UAVs that could be remotely destroyed (without causing collateral damage) would obviate the need to recover them when they crashed,

freeing up forces for other operations. UAV operations also need to be made more responsive to the user, so new concepts for airspace deconfliction need to be examines.

Warfighters had less experience with unmanned ground vehicles (UGVs), but saw areas in which they could be useful. UGVs to detect explosives would help warfighters conduct checkpoint operations more safely. UGVs (or perhaps hovering UAVs) that could search buildings quickly would also be very helpful; detection could be enhanced using an IR sensor. Such vehicles, though, would have to work quickly—warfighters were not inclined to pause for an extended period to operate an unmanned vehicle.

Warfighters also saw the need for persistent ISR. Warfighters reported that cameras to monitor base perimeters were desirable. Key supply routes could be consistently monitored for IED emplacement activity with stationary sensors (and conceivably constant UAV patrol). Also, as mentioned earlier, it would extremely useful to be able to monitor patterns in the movement of the civilian population.

It is difficult, however, to permanently emplace sensors outside of bases—they are easily detected and avoided or destroyed. Effective devices would have to be extremely unobtrusive and would benefit from being easily replaceable. Also, whether the sensor in question is inside a base or not, monitoring should be automated. Computers should cue personnel when a sensor detects something of note; the manpower is not available to constantly monitor the number of desired sensors.

Additional Capability Areas

Warfighters expressed the desire for a number of capabilities that do not fall in the broad categories described above. One key shortfall was in the area of personal protection. While the warfighters wanted improved body armor, they were adamant that more was not necessarily better. Their mobility and agility is already significantly impaired by the current armor and by the other equipment they must carry. The current level of protection should come at a lighter weight and with fewer constraints on movement. The level of protection should also be readily tailorable; more armor for a soldier standing at a checkpoint, less armor for a soldier out on patrol.

Warfighters also wanted improved capability to communicate with the local population. Competent and trustworthy local translators are hard to find. Current translation devices are unreliable and are mostly successful in the transmit mode. A two-way translation device would be extremely useful. Baring a truly reliable technical solution, improved language training for U.S. forces is needed.

Other types of training could also use attention. Some warfighters, though not all, expressed concern that some of their warfighting skills could erode while forward-deployed in an S&R environment. A high operations tempo kept most skills sharp, but artillery and armor officers posted at small bases, for example, did not have much chance to exercise their core competencies. Simulations embedded in military equipment, stand-alone simulators, and simulation-based desktop computer training suites could help in this regard, both for warfighters

in the combat zone whose equipment cannot be used and for warfighters at home whose units are a low priority to receive their full complement of equipment and resources for live training.

Lastly, warfighters saw the need for improved battlefield medicine technology. Sensors that gave leaders basic data on the health of their warfighters—on their current susceptibility to heat exhaustion, for example—would be useful. Warfighters were concerned, though, that the availability of such data could excuse officers and non-commissioned officers from their basic responsibility for their troops' well-being. They also emphasized that any health parameters might have to be ignored at a commander's discretion. Beacons that gave the location of wounded warfighters would also be helpful.

Discussion of Broad Themes

In each of the capabilities areas discussed, and in others besides, warfighters consistently raised several themes, mostly having to do with the pitfalls of introducing new technologies.

Too much information. Warfighters were extremely concerned that they and their troops not become over-saturated with information. In the estimation of the captains and senior sergeants to whom we spoke, privates and corporals generally did not need the ability to communicate with anyone outside their immediate unit, or have detailed awareness of anything beyond information passed to them by a platoon leader. Technologies would have to allow data to be filtered and tailored as appropriate for the user. New methods of operation could also help. As discussed earlier, an "information overwatch" warfighter could be tasked specifically with monitoring and assessing communications and data and keeping unit situation current. This concept could apply both to platoon-level operations and to higher echelons.

Too much to do. This is related to having too much information forced upon them. More technology means more tasks. There may be merits to giving every soldier a radio, or a data display, or the ability to send and receive text messages, or control of a UAV. But a soldier cannot do these things simultaneously, or on the move, or while maintaining full awareness of his surroundings, or while shooting his weapon. While specialization offers a partial solution—having an especially wired soldier perform "information overwatch" or have dedicated UAV operators—this diminishes the number of warfighters able to perform, for instance, their fundamental infantry duties as riflemen. This concern underscores the importance of keeping technologies simple and user friendly, as well as the importance of exercising discretion when providing new capabilities.

Reach-down. Warfighters were concerned that advanced communications and situational awareness technology would enable a high degree of micromanagement from upper echelons. The advent of excellent communications between CONUS and the theater of operations has already led to a similar phenomenon; senior officers complain of "the 7,000 mile screwdriver."[17] Were reliable long-range portable radios and BFT-type technology to proliferate to the soldier level, leaders at battalion and above would have ability to pass orders directly to squads or individuals and interrupt operations with requests for information. The *ability* to exercise control

[17] David Ignatius, "The Defense Secretary We Had," *The Washington Post*, 9 November 2006. Available at <http://www.washingtonpost.com/wp-dyn/content/article/2006/11/08/AR2006110802084.html>.

at the lowest levels could lead to the *desire* to exercise such control, diminishing the latitude enjoyed by junior officers and non-commissioned officers to achieve the "commander's intent." Further, such technologies, combined with video feeds, could give a false sense of immersion in the battle. Commanders in the rear could come to believe that they had a full appreciation for complex and rapidly changing events taking place miles away, and behave as though they were positioned to make decisions best left to men on the ground. An information overwatch warfighter could serve as a partial antidote to this concern. Data aggregation and assessment at the small unit level is more likely to be informed by a close understanding of the situation on the ground.

Operational Tempo. Warfighters were concerned that the benefit of new technologies would be outweighed by the time it took to employ them. This applies to C4 technologies designed to synchronize operations among units. Improved technology will, warfighters fear, lead to greater expectations for precise synchronization. Synchronization has its merits, but it will not always be wise to add complexity to operations and delay them to achieve close coordination.

Concerns about technology impeding tempo also apply at the tactical level. Waiting for a UGV to check out a building before entry, for instance, may place warfighters in greater danger than if they entered the building rapidly on their own.

Fielding of New Technologies/Systems. Participants were adamant that warfighters be properly trained on new technologies and systems being introduced to the theater of operations and that those technologies/systems be fully tested, assessed in terms of human-system integration and overall systems integration, and fully supported logistically. Technologies on which soldiers are not trained beforehand are unlikely to be used effectively. Much the same point was made during the SRO(I) research effort. A case in point is the MBITR. When the 1st-9th Cav received their MBITRs, they were briefly trained to use them for local communications.[18] It was not until they came in contact with a U.S. Marine Corps unit that the 1st-9th Cav found out their MBITRs could be used for Joint operations—like communicating with the crew of an U.S. Air Force AC-130 gun ship. Also, frequent iterations of technologies tax soldiers by requiring that they learn and relearn or adjust and readjust to new equipment.

As identified in Chapter 3, S&R operations have several unique differences from normal combat operations. When testing systems, these unique differences must be taken into account—e.g., testing of a new electromagnetic-based technology must take into account the complex electromagnetic background clutter of an urban area in day-to-day operations. Additionally, developmental and operational testing must be as rigorous for rapidly fielded technologies as it is for our large weapons systems. Fielding a counter-IED technology that jams local military radio systems, for instance, may offer immediate force protection from a particular IED threat but it will significantly degrade a unit's capability to efficiently and effectively coordinate military operations.

Human-system integration is extremely important to consider in S&R operations. Dismounted warfighters are weighed down with rations, water, ammunition and body armor and (in Iraq and Afghanistan) are operating in extreme temperatures against a sophisticated opponent. Any new

[18] Interviews with warfighters from 1st Cavalry Division, Fort Hood, TX, 15 November 2005.

technology that has questionable benefit (perhaps due to poor human factors engineering), reduces warfighter agility, or adds undue weight or discomfort will most likely be discarded when prepping for a mission. In some cases, participants claimed they used certain technology only because they were ordered to do so. Information overload is another critical consideration of human-system integration when fielding information systems to warfighters.

Full systems integration is also extremely important. Issues identified earlier in this chapter in terms of communications interoperability is one example of a need for this consideration.

Finally, logistics support is extremely important. For example, a technology which requires unique logistics support, say special batteries, creates an undue burden on a unit’s supply system and strains the warfighter, who has to carry an additional type of battery on a mission. Any technology which cannot be supported in terms of repair parts or maintenance personnel will quickly be discarded.

Chapter 5. Battle Command

A large number of very critical S&R capability gaps identified both in the preceding chapters and in SRO(I) relate to issues with communications and C2 systems. Concerns include the following: difficulty integrating complex urban operations; the inability to rapidly account for both combat and non-combat related effects of operations; communications gear that is not interoperable, sufficiently portable, or lacks reliable non-line-of-sight capability; the inability to track and identify dismounted S&R personnel in an urban environment; the need to track indigenous non-combatant civilians for control and situational awareness; the inability to integrate DIME and PMESII data into planning and decision making processes; and too few translators and effective translation devices. These varied capability gaps fall under the Army's functional concept of Battle Command. Given the importance of these capability gaps and their close relationship to Battle Command, the authors believed it would be of significant value to develop a deeper understanding in this area, in hopes of identifying even more specific capability needs. Thus it was decided to address Battle Command capabilities and gaps in greater detail in a separate chapter.

Battle Command Background

The first concept of Battle Command in 1993 has been refined in successive versions of the Army's capstone operations manuals, initially FM 100-5 and later FM 3.0, culminating in the just published 2007 FM 3.0, Full Spectrum Operations. The concept of Battle Command is uniquely an Army rather than joint doctrine concept, yet it is fully consistent with joint and other service doctrine.[19] It is also readily synchronic with all current and future joint warfighting systems, including DOD's principal C2 information system, the just emerging Net Enabled Command Capability (NECC).

Battle Command is the art and science of applying leadership and decision making to achieve mission success.[20] It includes controlling operations and motivating soldiers and their organizations into action to accomplish missions; visualizing the current and desired future operational states, then formulating concepts of operations to get from one to the other at least cost. It also includes assigning missions, prioritizing and allocating resources, selecting the critical time and place to act, and knowing how and when to make adjustments during the fight. Battle Command emphasizes the art of command in the personal decisionmaking processes of the commander: his or her visualization of the mission and operational area, description of intent and directing of operations—as distinct from the support roles of staffs and enabling systems. [21] It also focuses on the command of forces under the most demanding and arduous conditions against a determined enemy. Battle Command is not particular to S&R or other subset of warfighting operations; it guides all operations in warfare. As such, it provides the context in

[19] JP 3.31 C2 for Joint Land Operations and MCDP 6 Command and Control
[20] TRADOC Pam 525-66 (Force Operating Capabilities), Chap. 4, Sec. I (Battle Command), Para 4.1b (Joint/Army Concept Linkage), 1 July 2005, 16.
[21] Army FM 3.0 Full Spectrum Operations, Chapter 5, 5-2 (14 June 2007)

which the Army must address the communications, command, and control S&R capability gaps identified by this report and SRO(I).

The most immediate S&T reference for Battle Command investment priorities are the Force Operating Capabilities (FOC) described in TRADOC Pam 525-66,. FOCs are expansively described groupings of warfighting capabilities derived from capability gaps identified for the current force (the Capabilities Gap Analysis or CGA) and future force (the Capabilities Needs Assessment or CNA), as well as technology shortfalls determined by comparative analyses of current investment plans and the Army Technology Objectives (ATOs). Battle Command, one of 11 designated FOCs, is tied to the Joint warfighting concepts of Joint Force Command and Control and Joint Net-Centric Operations.[22] The Battle Command FOC is divided into six Capstone Capabilities areas: Command and Control; Army Client to the Global Information Grid; Network Operations; Decision and Planning Support; Information Operations; and Information Protections. In turn these Capstone Capabilities are linked to specific tasks in both the Joint and Army Universal Task List (AUTL) and the Universal Joint Task List (UJTL). Under this methodology, S&T initiatives aimed at meeting Battle Command capabilities are conceptually grounded across the Army as well as with Joint Force warfighting development.[23]

Since the SRO(I) report was produced in late 2006, two authoritative documents have been published that further elaborate the Army functional concept of Battle Command.[24] The first, TRADOC's *The U.S. Army Functional Concept for Battle Command 2015-2024*, emphasizes the commander's central role in Battle Command. It articulates the doctrine, organization, training, materiel, leadership and education, personnel, and facilities (DOTMLPF) requirements to develop and assist commanders in their execution of Battle Command tasks and implies the need for significant changes in the way the Army organizes, educates and trains, sustains, leads and mans its forces and primary training facilities.

The second doctrinal publication is the Army's new *Full Spectrum Operations* manual. It dissects Battle Command into its sub-functions and alludes to a host of systems and technologies that are needed to revamp current command processes such at the Military Decision Making Process (MDMP). It also deepens our understanding of how Battle Command will be applied and what it will require to meet expectations for Battle Command of Future Forces.

Battle Command literature tends to focus on tactical operations at the brigade level and below, which is the cultural core of the Army: concentrating on soldiers, their mission and their immediate environment. There are relatively few tactical commands above brigade and the modular Army concept also emphasizes operations at the brigade level and below. The few commands at division, corps, task force and component levels operate on extended scopes of time and distance relative to brigade commands, and have more access to sophisticated joint C2 technologies. However, Battle Command at and below the brigade is necessarily concentrated in time and space and is constrained by limited access to information and commodities such as bandwidth. It is operations at this level where S&T requirements are most challenging.

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[22] TRADOC Pam 525-66, 6-8.

[23] See the Army Science and Technology Master Plan (ASTMP) dated March 2007, 1-4

[24] See Army FM 3.0 Full Spectrum Operations (see Chapter 5: Battle Command), 14 June 2007 and TRADOC Pam 525-3-3 The U.S. Army Functional Concept for Battle Command 2015-2024 (Version 1.0), 30 April 2007.

Unique Battle Command Requirements of S&R Operations

Many of the technological challenges of Battle Command in S&R operations are the same as for combat operations. Technologies to optimize information and communications channels (i.e., bandwidth utility, information processing, tagging and integration); technologies to sort, post, and manage information; decision support tools that enable Battle Command on the move without disconnecting from key information and communications sources—all enable Battle Command in stabilization and reconstruction operations scenarios just as they do in combat.

However, other Battle Command requirements are unique or stress different priorities during S&R operations. S&R operations generally involve tracking more, and more varied enemy and friendly force actors than do conventional combat operations. They also require integration of a broader range of actions and their intended effects across diplomatic informational and economic campaigns as well as military. How can commanders track, analyze and make decisions on such information, rapidly? How will leaders manage, use, or even become aware of all relevant information needed to affect timely battlefield decisions? Are there automated ways to bring the right, timely information to commanders, and how will they, within the limits of human capacity make better decisions based on all available inputs? Where is the threshold between enough information and too much information? These issues at the tactical level require greater information specificity as the commander operates in compressed space and time scales yet needs (or would like) reliable, continuous information of a very precise nature. In view of these challenges, Army technology investments should take special account of the demands of Battle Command in S&R operations as follows.[25]

- *Behavioral Sciences*. Battle Command underscores that *the commander* is the true center of network-enabled decision making. Staffs, headquarters structure, technology and networks are but essential supporting capabilities.[26] This emphasis stresses the need to successfully identify and hone the skills of individuals who will exercise command. Yet S&T investments in behavioral psychology can be poorly understood or seen as less critical because they are long term, lack high-visibility hardware or software products, and usually have no commercial or industry advocates. However, investment in behavioral science is essential to ensuring the best talent and the deepest bench for leadership in tactical level S&R operations.

  Important behavioral science research is already being done,[27] however, much more is needed, especially related to Battle Command knowledge and decision making in integrated S&R operations. Rapid, accurate decision-making in S&R will depend on the judgment of the Army's youngest, relatively least experienced commanders at the small unit level – both officers and non-commissioned officers. These leaders must be able to integrate social, cultural, diplomatic and other data into immediate decisions during S&R operations. Related behavioral research should address the limitations of human decision

[25] Information in this section derived principally from day-long discussions at CECOM, Fort Monmouth, NJ with a technology team led Mr. Paul Manz, Technical Director for PM Battle Command, CECOM.
[26] See William S. Wallace, LTG, USA "Network-Enabled Battle Command," *Military Review,* May-June 2005, 2–5.
[27] Discussions with Psychology Department and Computer Science faculty members at USMA in January and May 2007.

making and data assimilation in complex, time and technology constrained S&R situations.

- *Visualization and Decision Support requirements for S&R.* The fundamental tasks of Battle Command include visualizing, deciding on and describing (communicating) a selected course of action along with a commander's intent, and then following through by directing the operation. These tasks require visualization, decision support and communicating tools. S&R operations require unique attributes for visualization and decision support. For example, S&R specific visualization symbology would indicate concentrations of civilians or sensitive infrastructure as restrictive terrain for rapid response forces.

  When given a mission, S&R commanders and staffs need computing technologies that provide rapid terrain modeling of a specific operational area complete with the most up-to-date data on terrain modifications inflicted by recent combat operations (e.g., impassable roads, flattened buildings, and destroyed bridges) as well as S&R related sites (key facilities, institutions) to help them visualize the terrain from an S&R perspective. Ideally map-oriented displays can provide not only 3D information but could also incorporate a 'time sliding' feature to compare alternative courses of action as they might unfold.

  Decision support tools must be able to continuously aggregate all relevant information during planning as well as execution. Prototype running estimate software (RES) based on Blue Force Tracking information and red force intelligence promises significant advances in decision support during mission execution. However RES products for S&R must also take into account contextual information. For instance, variations in civilian activities due to holidays, store and market openings and customary work hours would affect route planning for reaction forces. Moreover, S&R missions are often carried out by smaller unit elements operating over a wide area as opposed to a single axis advance. These realities pose different if not greater technology challenges in software development for S&R operations than for combat operations.

- *Data Initialization Requirements Expand for S&R Operations*.[28] A primary purpose of data initialization is to establish common understanding of shared data. In S&R operations data stream types multiple as non-combat information demands increase (e.g., infrastructure, civil institutional, social, political and economic information). Likewise, the numbers and types of users attempting to share information multiply: coalition partners may increase, more interagency partners join the military task force, and local officials plus others will need access to information on the network. Both the increase in data and the increase in users place a higher premium on being able to share data.

  In S&R operations non-military elements join the task organization as military units undergo task re-organization, expanding and re-configuring the Battle Command network. Even if technically interoperable, the expanded set of network users will not be

[28] Information for this section is drawn from an excellence paper by Ronald B. Sprinkle (SAIC) and Christopher Black (Colsa Corporation), *Joint BC & and Simulations Systems Initialization Process*

truly interoperable unless they have a common understanding of the data to be shared for effective Battle Command. For example, until a recent fix it was routine that FBCB2 could not message to many ABCS other systems due to FBCB2's limited database. Another acknowledged problem is that systems that do not recognize particular data often display the data mismatch (e.g., a new unit's location) as "unknowns."

Data categorized as Battle Command specific data includes all data related to course of action analysis, mission rehearsal, mission monitoring, and control of robotic assets, including all data related to operations, plans and orders plus appropriate graphics and matrices. However, for S&R Battle Command, data categories expand even further to include such environmental specific data as facilities and infrastructure, which is critical to S&R mission planning, rehearsal, monitoring and execution.

ISR Integration Challenges in S&R Operations. The nature of S&R operations also demands a wider focus for ISR. In addition to a continuing need for enemy information (e.g., early detection of an insurgency), S&R operations require a broad range of essential information that is not emphasized in combat operations. A broader, more specific set of information needs must be specified in the Commander's Critical Information Requirements (CCIR) portfolio.

CCIR about areas to be stabilized include the nature of pre-conflict policing and crime, influential social networks, religious groups, and political affiliations. Financial and economic systems as well as key institutions and how they work are other critical elements of information. Mapping these systems for specific urban areas will be tedious though much data is already resident in disparate databases.

Technologies are needed to collect and organize existing information and identify gaps that future collection investments must close. In some cases, modeling and simulation can generate probabilities for success in unknown regions based on socio-economic systems in known areas with similar characteristics. Infrastructure systems for power, water, transport, sewage, telecommunications and other services represent another critical set of information requirements for commanders engaged in stabilization and reconstruction operations.

- *Battle Command on the move (BCOTM) technologies.* The capacity for the commander to move to the point of action without becoming disconnected from essential information systems has become one of the most sought after technologies on the battlefield; and at lower unit levels the need is no less during S&R operations. Although higher headquarters can expect to become more static during S&R than during offensive combat operations, commanders of lower level units tend to become more mobile, continuously visiting areas to maintain visibility and to direct short term, targeted operations under the umbrella of overall sector control.

  In particular, commanders will utilize mobile Battle Command systems (ground or airborne) to maintain situational awareness of conditions as well as to use their on-site presence to influence by their on-site presence both military and civil-military operations.

Small unit leaders will often dismount when conducting S&R operations. These Battle Command situations require technologies that provide mobile secure networking; miniaturized, stripped down COP displays; universal blue force position locating; and reliable, secure voice communications.

- *Communications Technologies for S&R Battle Command.* While there is significant congruency between communications capabilities for S&R and those for other types of operations, S&R operations place a particular premium on reliable communications at the small unit level, including mounted and dismounted team-size elements. S&R operational concepts call for "presence" missions such as check points, traffic control, roving patrols and work teams (e.g., medical aid, reconstruction, institution support) dispersed across complex urban or semi-urban terrain, and comprised of robotic systems as well as troops. To support the communications needs of S&R committed forces the Army will need to continue toward its goal of Future Combat Systems (FCS) and Joint Command and Control (JC2) communications, and invest in interim improvement to selected legacy systems that will serve as bridging systems for many years to come. Extending the network to the so-called "last tactical mile" is still very much in the future, with the exception of some Special Operations Force capabilities. For example, no appreciable quantities of the Joint Tactical Radio Systems (JTRS) – an FCS system – are anticipated to be operational before 2015, according to recent reports. For now, the Army should strive to integrate legacy systems and select COTS solutions to meet near to mid term communications integration requirements.

  An important issue associated with communications in S&R operations is when teams leave vehicles. These scenarios generate requirements for vehicle communications and associated information systems to be detachable from vehicles and used in a dismounted role. In addition to requiring the detachable system to be small and lightweight, the systems must be rapidly convertible with requisite antennae and power supplies. The U.S. Army Communications-Electronics Research Development and Engineering Center (CERDEC) is having some success addressing these issues with systems operating approximately 100 meters from their original vehicles. While this may signal an important breakthrough, S&R operations will require communications systems to operate for extended periods many kilometers away from their vehicle mounts, i.e., as fully autonomous whether dismounted or vehicle mounted.

  As S&R operations become more data intensive, more bandwidth will be necessary for units at all echelons. We now are able to utilize only about 6 percent of channel capacity. It should be possible to develop the means to reallocate frequencies in real time to utilize full channel capacity.[29] There is a very recent report of a technique to increase communication channel utilization by a factor of three by using the evanescent waves (essentially, waves leaking out of the wave guide) to operate a receiver array at one thirtieth the wavelength of the radiation.[30]

[29] H. Chang, technical discussion at ARO, Research Triangle Park, NC, 22 February 2007.
[30] G. Lerosey et al, "Focusing Beyond the Diffraction Limit with Far Field Time Reversal," *Science* 23 February 2007.

The solutions to such communications and network challenges will take place within LandWarNet, the Army's umbrella concept for future Army networks. The Army's communicators, programmers, S&T community and leadership are committed to joint networked operations for both warfighting and S&R operations, and are deploying support communications technologies that have been designed for this future concept. The first requirement was to validate the primary systems already programmed and those in the developmental pipeline as being essential to the Future Force. Validated systems should continue to receive strong endorsement by the Army S&T leadership. Some LandWarNet systems included in this category are: Enhanced Position Location Reporting System (EPLRS), JTRS, Warfighter Information Network-Tactical (WIN-T), Army Airborne Command and Control System (A2C2S), and Satellite Communications (SATCOM). These have been validated as essential to the Future Force and as the most effective, readily available technologies for combat as well as S&R operations.

Army investments in DOD's strategic network, Global Command and Control System—Army (GCCS-A), as well as its own operational level Army Command and Control System (ACCS) and tactical level FBCB2 must keep these systems up-to-date even as they migrate toward NECC and FCS communications systems. LandWarNet should become fully interoperable with Navy's ForceNet and Air Force's ConstellationNet with minimum cross-network access delays. The technologies that support this and similar near term priorities are critical to S&R operations. The Army should invest in interim technologies, especially those that offer technology upgrades to existing, proven programs. Such decisions provide enhanced capabilities to address the challenges facing soldiers today in S&R operations.

- *Multinational Connectivity and Secure Networks.* S&R operations place an especially high premium on the capability of U.S. forces to network and communicate with host nation forces or with forces from allied nations. In coalition operations Battle Command interoperability is key, yet it is not uncommon even for our closest allies to require the use of liaison teams due to the absence of interoperable information and communications technology (ICT). The challenge of interoperability has been daunting and longstanding. However the recent shift to a common data architecture rather than common ICT systems will allow dissimilar systems to share information. To that end, a group of 25 nations called the Multinational Interoperability Program (MIP) is in the process of adopting the Joint Consultation Command and Control Information Exchange Data Model (JC3IEDM), based on an accepted IEDM in use by NATO.[31] Encouraging this initiative should be a high priority for the Army.

  Connectivity with coalition partners is usually limited to unclassified information due to security policy concerns as much as for technological incompatibility. However, one part of an elusive solution is technological: the requirement for reliable and trustworthy automated multi-level classification systems. Such systems could open most networks to handling different levels of classified information simultaneously. In Afghanistan, for example, forces under U.S. command as well as under NATO International Security

[31] LTC Andre Cota-Robles, USA, *Finding Common Ground,* C4ISR The Journal of Net-Centric Warfare, Vol. 6, No. 3, April 2007, 40-41.

Assistance Force (ISAF) operate together via Centrix data and voice over internet protocol (VOIP) connectivity as well as by Defense Secure Network (DSN) to Interim Secure Voice Network (ISVN) links. Cleared NATO users have access to NATO Secret and ISAF Secret information. However, the systems they can access are only authorized to share unclassified traffic due to governing Information Sharing Policies agreed to by using nations concerned about information security. Multi-level network access would allow all users secure access to the information they require irrespective of the access level of other network users.

Providing access to Battle Command networks by many entities outside the Army highlights the demand for multilevel network security and for automated or rapid selection/de-selection of network participants without compromising network defense or information assurance. Without such technological sophistication slow procedural access will still be dominant, as will use of labor-intensive work-arounds such as couriers and liaison teams. In addition, the rapid, automated recognition and authentication of new entities on the network is a related important requirement.

Joint force integration in S&R operations will be accommodated by the continuous availability of voice/video communications and data connectivity over secure, reliable systems to link seamlessly from fixed headquarters and forces to small units and platforms on the move. Coalition force integration indicates the continuing demand for systems such as Centrix (Iraq/Afghanistan) and Cronos (Balkans/Afghanistan) that are outside DOD communications channels but able to support classified information.

Communicating and sharing data with NGO's and key contractors is another characteristic of Battle Command in S&R operations. At times, commanders will also need to communicate and share information with local officials or private sector leaders. The usual methods for such contacts are through face-to-face meetings or the use of unclassified cell phones. However better integration options should be available to commanders.

Interoperability of coalition systems will continue to be a technological as well as an information security policy challenge that limits the desired integration of allied forces. This poses greater problems for S&R Battle Command as more coalition partners are brought into the force, either for political reasons, niche capabilities or simply to share the burdens being borne by U.S. forces. Until these challenges are overcome the solution of choice with even our closest allies remains the traditional liaison team.

- *Force Control Technologies.* The controlling or directing of forces is fundamental to Battle Command, and commanders in all operations have come to expect current blue force location information in real time. Therefore it is no surprise that Blue Force Tracking technology has transformed the presentation of friendly force information on the COP. BFT is far from universally deployed and understandably commanders want more systems, including man-portable BFT's that can be distributed down to the team level.

As noted in Chapter 4 BFT technology does have shortcomings that will be important to overcome in future designs. Latency in BFT location reporting and text messaging features are well documented. System incompatibility issues (different data formats, proprietary software, etc) are another concern. Finally, with the continuing proliferation of BFT, techniques will be needed to suppress display clutter and manage COP information presentations to meet commanders changing requirements.

Force control technologies must look beyond the current BFT to other enhancements. Commanders at times need to understand not only where a unit is but why it is where it is. Information on enemy contact, mission progress, movement limitations imposed by terrain or fuel status should be available when selected. With such information commanders and staffs can take action to adjust supporting resources to maintain operating tempo. Other enhancements could allow COP displays to alert commanders when units approach control measures such as fire coordination lines, and could provide more detailed information (e.g., unit leader identification, UAV dwell time/fuel state, arriving unit network contact info, etc).

- *Airspace management.* Airspace de-confliction often becomes even more complex in S&R operations than for combat. Rules of engagement are more restrictive, unit areas are more fragmented and the make-up of friendly forces requiring airspace use becomes more diverse with additional coalition and interagency partners. Moreover, the demand for ISR support from UAVs, close air support from manned or unmanned platforms, or the flight paths of ground-based fire support projectiles compete with greater use of military aircraft and the re-start of civilian air traffic. The competing imperatives for safety and responsiveness limit the utility of many systems. For instance, UAV use may be approved at or above brigade level in order to coordinate manually with other airspace users, though many systems are designed explicitly for small-unit use.

  The Army should push the limits of technology-assisted airspace control. Currently, airspace management is primarily a matter of procedural altitude separation: above a given altitude the Air Force is the manager and airspace use requires time-consuming joint coordination. Such procedural control could be superseded by automated or semi-automated control if a system can be designed to create a multi-tiered electronic mesh or web over a given battle space area. Mesh-programmed UAVs would enter the computer controlled mesh like commercial aircraft on the civil air route structure, fly via the mesh to their designated protected loiter area and depart the mesh into less controlled yet safe airspace until ready to return to base or take on a new mission. Such a system could optimize airspace availability for all users and should be designed for rapid re-programming to accommodate calls for fire or other combat priorities. Separation between UAVs and helicopters operating in proximity at low altitudes would require additional consideration for air turbulence effects, especially on smaller UAVs.

- *DIME-PMESII and Battle Command.* In modern stabilization operations commanders must always be aware of the interacting perturbations of DIME engagement actions being employed by friendly forces to achieve desired outcomes across the PMESII environments of the operational area. Current science does not yet fully understand and

cannot reliably quantify all the variables in the DIME-PMESII equation, which are complex and continuously shifting, interdependent systems.

Although the task of defining metrics remains, the near term objectives should be to incorporate as much DIME-PMESII data into the S&R COP as possible while continuing research (including lessons learned from S&R operations) into these complex systems. One such experimental system is the Effects-Based Assessment Support System (EBASS), which has shown promise in several theaters. EBASS compares a desired end state with the estimated PMESII effects of DIME specific actions, such as the use of deadly force by Blue Forces on the broader political, economic and social situations also critical to mission success. EBASS is not predictive, but can only document limited, after-the-fact results using an Indicators and Measures of Effectiveness equation to build a database of related effects. In the use of deadly force example above, understanding PMESII effects could help define when to apply flexible Rules of Engagement (ROE). The DOD is putting more emphasis on developing and fielding DIME-PMESII predictive systems, like the Army's Joint Non-kinetic Effects Model (JNEM) training tool, DARPA's Conflict Modeling, Planning, and Outcomes Experimentation (COMPOEX) decision support tool, and Joint Forces Command's Synthetic Environments for Analysis and Simulation (SEAS) decision support tool.

Despite limited knowledge of interactive effects, much is known about the *independent* effects of DIME components, both generally and in particular cultures and regions. The next step is to build computer models that can show interactive DIME actions based on decisions by commanders and civilian counterparts. Such models would enable interagency leaders and military commanders to synchronize and sustain integrated effects. Models should be able to 'learn' over time from after action inputs, improving the sequence of unified DIME actions to produce better and better effects on PMESII systems.

Although near term solutions may not be on the horizon, there are a number or initiatives that the Army's S&T leadership should support. The more prominent of these examined during this study include the Joint Non-kinetic Effects Model (JNEM) training simulation for S&R operations; the Theater Effects Based Operations (TEBO) Advanced Concept Technology Demonstration (ACTD); and DARPA programs like Conflict Modeling, Planning, and Outcomes Experimentation (COMPOEX) and Deep Green to improve PMESII modeling and simulation capabilities. In both actions (across the DIME domains) and reactions (across PMSEII outcomes) the lower one goes in the organization the less planning and the more rapid execution of higher HQ policies one will find. The more effectively Battle Command technologies can track actions and anticipated reactions as being in concert with a given commander's intent, including those actions contemplated by subordinate units, the better synchronized operations will become. With S&R requirements in hand, we will now discuss the current system capabilities, to be followed by a section on the resulting gaps for Battle Command.

Current System Capabilities Enabling Battle Command

Battle Command is enabled by three core components: C2 systems, communications systems, and computers/computing systems. Each component's capabilities must extend into the operational and tactical environments of S&R operations. In that same environmental context, technologies for Battle Command must support the related S&R operations tasks of: information operations; DIME campaign integration; connectivity with joint/coalition/interagency force multipliers; and the networking of ISR (intelligence, surveillance and reconnaissance) resources to rapidly visualize the area of operations and course of action options, describe command intent to subordinate and supporting forces, and direct operations.

While it is important to keep in mind that the heart of Battle Command remains the personal capabilities of the commander, enabling systems and technologies are also essential to the function of command. Therefore all systems support successful execution of Battle Command tasks across all DOTMLPF domains are of particular interest; we address the overall suite of Battle Command systems and one recent enabling innovation below.

- *The Army Battle Command System (ABCS).* ABCS was established in the 1990s and will be the mainstay to enable Battle Command for many years into the future. Therefore it must be kept up-to-date until the migrations to NECC and FCS are complete. ABCS is the collective array of communications and data network systems supporting the information and communications requirements of commanders. Via the Battle Command System (BCS) Server, 10 independent network systems are links into any headquarters and to each other various component sub-systems (e.g., EPLRS, JTRS, SINGGARS, WIN-T, SATCOM, etc) to support the commander. The family of 10 battle command network systems are:
  - GCCS-A – strategic C2 network
  - Maneuver Control System (MCS) – primary high level tactical planning/C2 network
  - FBCB2 – primary tactical C2 net
  - Integrated Meteorological System (IMETS) – weather network
  - Digital Topographic Support System (DTSS) – terrain mapping system
  - All-Source Analysis System (ASAS) – intelligence support network
  - Tactical Airspace Integration System (TAIS) – airspace management system
  - Advanced Field Artillery Tactical Data System (AFATDS) – fire support network
  - Battle Command Sustainment and Support System (BCS3) – logistics operations
  - Air and Missile Defense Workstation (AMDWS) – air defense operations

  The AMDWS and AFATDS networks play limited roles in current S&R operations in Iraq and Afghanistan due to the infrequency of major combat operations. However, other ABCS sub-systems are vital to S&R operations and face unique S&R-related information demands.

  Components of ABCS, including MCS and FBCB2 which are compatible with CPOF, JTRS and FCS, will be relevant to the Future Force. ABCS, however, will ultimately merge into DOD's NECC at strategic-operational levels and at the tactical level into a future FCS system.

The S&T investment in ABCS components as the Army migrates to network enabled operations must target the need to maintain forward and backward interoperability as well as address a number of broader challenges. One is the transition from analog to digital communications systems. Newer units, such as Stryker Brigade Combat Teams (SBCTs) are fielded with digital C4 capabilities while the majority of units still operate on analog systems, requiring use of a "digital bridge" element to affect interface.

Another challenge is the DOD wide conversion from IPv4 to IPv6 capable systems over the next several years. That changeover will require 'dual stack' transport layers for connectivity to units, partners and allies not IPv6 compatible; a situation expected to continue for many years. Finally the sustained period of extraordinary operational tempo demands diverts leader attention and Service resources to fill immediate operational needs and equipment re-set.

In order to deal with these challenges, there are a number of programs being pursued by the PM, Battle Command at U.S. Army Communications-Electronics Command (CECOM), working together with the U.S. Army Combined Arms Center (CAC) to improve the execution of Battle Command. One such effort is CPOF, discussed below. Other initiatives are detailed in the next chapter.

- *Command Post of the Future (CPOF).* The DARPA-based CPOF initiative has emerged as a popular tactical Battle Command tool throughout the Iraq theater for decisionmaking, collaborative planning and COP visualization in a compound S&R-counterinsurgency (COIN) environment. CPOF first deployed with the 1st Cavalry Division in 2004 and is now a program of record being considered by the Marine Corps as well as the Army. There are approximately 700 CPOF systems in Iraq from Corps to battalion level and over 800 systems worldwide. The new CPOF 3.0 supports more workstations (60) while using only one-third the bandwidth for a division level fielding. CPOF is a case study in successful acquisition and fielding outside the standard Joint Capabilities Integration and Development System (JCIDS) process.

  The key to CPOF popularity is its ease of use as a visualization system for planning as well as real time situational awareness and distributed collaborative execution management. CPOF includes VOIP communications and map centric two and three dimensional interactive graphics. It maintains an up-to-date COP by importing data from ABCS component such as the MCS.

  The triple screen CPOF system has expanded its mobility and functionality with a down-sized single screen version on ruggedized laptop hardware. The Army is now engineering CPOF to be fully interoperable with other ABCS programs rather than requiring the human-directed input of data from other systems. When fully incorporated into an enterprise environment data will flow freely from all relevant systems and be available to CPOF users for visualization and planning.

  For S&R operations, one additional capability that should be incorporated into future CPOF versions is running estimate software such as is now being prototyped by the

Army's Battle Command Battle Lab at Fort Leavenworth (BCBL-L) in cooperation with CERDEC.[32] Not only would CPOF provide its current plan rehearsal capability but it could compare the plan with automated Blue and sensor-provided Red inputs during actual execution. Commanders can then influence the operation as it unfolds. At present running estimates are limited to offense operations that take place over a few hours.

Another enhancement critical to S&R operations would include estimate software that can depict S&R operational plans and execution visualization over days and weeks, or even longer. For a complete S&R COP, CPOF will ultimately need to incorporate DIME and PMESII factors as noted in the next section.

System Level Technology Gaps Impacting Battle Command in S&R Operations

As already stated, the recently published Battle Command concept and doctrine does not address S&R operations separately from combat operations in terms of technology requirements. Reports from the field and other evidence, however, make clear the specialized demands of Battle Command in S&R operations. In particular, there are technology requirements for unique intelligence, decision support modeling, more diverse connectivity, and less hierarchical communications over more widely deployed, smaller force elements. The longevity and magnitude of Army engagement in S&R operations indicates that the related technology requirements should be given clear visibility in relevant program investments.

Some solutions, such as accelerating development of running estimate software for S&R applications (and migration to the next version of CPOF) are straight forward. Others, such as the challenge of developing high fidelity predictive models of DIME-PMESII interdependencies are long term experimental undertakings with no certain outcome.

There is a lot to do. Many programs of record undertaken for Battle Command based on combat requirements can be justified even more so for S&R operations. Non-line-of-sight (NLOS) communications is one such example given that small units will be more often dispersed in urban areas that interfere with LOS communications. Other programs, such as BCOTM may be less important at higher unit levels in S&R operations, but at brigade level and below it becomes even more critical to Battle Command.

The biggest overall Battle Command concern in S&R operations will be the capability to stay reliably connected to sources of relevant information and to other forces. Also, much of the success Army forces will realize in S&R operations depends on how these Battle Command capabilities are developed and how they are integrated in doctrine, training, and planning. The Army's BCBL-L already plays a central role in meeting these tasks. BCBL-L integrates ideas, develops future concepts, conducts experiments and prototyping of technologies and concepts, and manages applications' evolution.

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[32] Briefing and demonstration by BCBL-L and CERDEC Liaison Officer at BCBL-L Prototype Lab, 1 May 2007

An assessment by BCBL-L of the most pressing science and technology gaps in Battle Command and its enabling systems for S&R operations include the following:[33]

- *Understanding how commanders develop and execute battle-focused leadership and battle judgment*. There are shortfalls in research on the behavior of commanders and in the preparation of commanders to perform the battle command competencies of planning and execution of operations. Moreover there is limited knowledge about how to consistently replicate the identification and development of successful commanders, especially at the small unit level where inexperience is a larger factor in mission succeed or failure. The Army needs a benchmark for defining Battle Command competencies and for maximizing its investment in Battle Command enabling programs and technologies. Benchmarking will ensure a high caliber of battle commanders for the future by helping the Army understands how to prepare commanders to execute Battle Command, which goes far beyond exercising Command and Control.
- *Future Force Worldwide NLOS BCOTM.* There is a lack of fielded systems for reliable, secure on-the-move joint networked communication, collaboration and situational awareness capabilities. These challenges would include successful development of lightweight radios, self-healing dynamic networking, semantic interoperability of data, optimized bandwidth (e.g., mobile, low bandwidth IPv6 tactical systems), antenna co-site interference elimination, automated spectrum management, and continuous updating computer network defense systems.
- *Data Initialization*. There is still a long way to go for the Army to achieve interoperability of current and future systems such as ABCS, FCS, JC2 and NECC. Interoperability requires data be configured to the agreed Command and Control Information Exchange Data Model (C2IEDM). When achieved, dynamic, automatic and flexible information distribution and processing will be possible. Initialized data will flow across networked systems to provide a continuously evolving common operational environment and consistent, coherent COP.
- *Multi-Level Network Security*. There is a need for multi-level security in C2 systems – the ability to exchange C2 information on the same network and ensure that users are only given access to appropriate levels of classification. The goal should be one system network for all classification levels.
- *Future Force Decision Support Models for Complex S&R/COIN operations*. There is increasing demand for advanced decision making models such as the Coalition Joint Spectrum Management Planning Tool (CJSMPT), the Real-Time Adversarial and Intelligence Decision Making (RAID) tool, Decision Aids for C2 of Unmanned Assets, and the NECC model. These and other systems are under development and should be further tested for best of breed investment.
- *PMESII Predictive Analysis Tools*. Current science can only generate a range of plausible outcomes for the effects of DIME actions. We need better models of the system dynamics across PMESII and a better understanding of how military actions in particular might impact beyond the military model. Present science cannot predict outcomes due to limited understand of the population of possible effects and their interdependencies. One DIME-PMESII effects tracking model that has been used in Afghanistan is EBASS. Indications from that first initiative are that far more research is required to reliably

[33] From briefings and discussions with LTC Robert DeHaan, USA, Chief, S&T at BCBL-L on 14-15 March and 1-2 May, 2007 at Battle Command Battle Lab Ft. Leavenworth, KS

predict outcomes of even military actions let alone actions in other domains. Efforts like JNEM, COMPOEX, and SEAS should show promise.

- *Automated 2-Way Portable Translation Systems.* Overseas operations inevitably involve language barriers that are more acute in S&R operations due to the essential interface with indigenous populations. Systems are needed to automatically translate in natural voice or text to and from languages on site in real time and in cluttered background noise environments
- *Alternative to GPS*. Forces operating in complex urban terrain need an alternative to satellite-based systems for location and navigation, especially in GPS-denied areas (e.g., inside buildings and underground structures). The gap-filler systems should be foreseen as the follow-on to BFT and an alternative to GPS reliance should that system be degraded by natural limitations, failure or attack. In such situations S&R commanders must have an alternative means of determining three dimensional geo-locations for friendly, enemy and non-combatants in complex, urban and subterranean environments.
- *Enhancing C2 Operational Capabilities in a Counter IED Environment*. Experience shows that counter IED systems and Battle Command systems operating in proximity can degrade each others performance. As effective counter IED technologies become more powerful users of the electro-magnetic spectrum for Battle Command and wireless counter IED systems must be de-conflicted or shielded from reciprocal interference.
- *Current Force Identification Quality of Service*. Inherent latency in BFT technology that relays location and text messaging information can make this popular technology unreliable or even misleading in fast moving operation scenarios.
- *Integrated Tactical Network Operations Management*. This is the integration of network management, information assurance, and flow management tools into a single automated network management suite. The requirement is for the capability to plan, monitor, assess, secure, and visually display the status of network at the tactical level.
- *FBCB2 Store and Forward Capability*. FBCB2 does not retain text messages when operators are not within radio range of the sender or the system has been turned off. FBCB2 operators need to be able to retrieve messages that were sent while their systems were turned off/out of range as well as when they log onto a different FBCB2 platform.
- *Hybrid Communications Networks*. Improved communications are needed for future Battle Command data loads and mission requirements. Current tactical communications networks cannot accommodate the growing number of digitized platforms and the amount of data that is being generated together with the geographic dispersion of the systems. The future will bring about hybrid communications networks that include various LOS and celestial systems. The Army needs to invest in analysis, modeling, and simulation to understand how these systems can speed the routing of data at the tactical level.
- *User Interface/Presentation — "Liquid" Information*. Data must be readily subject to manipulation (i.e., in so called liquid form) such that commanders can access, view, configure, and tune data for visualization, describing, directing and workspace management in ways that support their thinking. In the visualization process, commanders should be assisted by computers in sketching and gesturing to express thoughts and understanding to others. For example, translating non-standard graphics to standardized symbology helps automate the translation of commander's intent-type graphics into standardized formal symbology for subsequent operational execution and

interoperability. Research in context-aware assistive computing will help model and further develop accurate and robust sensing, filtering, aggregation, and visualization capabilities. Research is also needed in human-computer interaction. For example, to explore if three-dimensional rendering detracts from a human's ability to interpret certain types of data/information and/or data/information trends. Areas for more research on user-data interface might include:

- Maximizing flawless throughput of tasks to others
- Minimizing virtual training
- Minimizing cognitive overload in processing information
- Improving user interface consistency

Chapter 6. Some Technologies of Interest

The last four chapters identify a list of capability needs derived from interviews, surveys, use case analyses, and an in-depth analysis of a particularly critical area, Battle Command. In all cases, these chapters focused primarily on capability needs. In this chapter we review promising developments in seven broad areas of science and technology: Electronics, Sensors, Power Sources for the Individual Soldier, Basic Research on Advanced Materials, Combat Casualty Care, Robotics, and System Level Research in Battle Command. While these science and technology areas apply to a wide range of military and civilian activities, each could produce technologies critical to filling the Army S&R capability gaps we have identified. We review these seven technology areas forecasting likely developments therein. The areas are at different levels of maturity; some are now being actively pressed in Army S&T programs, others are in very early stages of basic scientific work.

Electronics

Electronics are ubiquitous on the battlefield—in communications and computing gear, in detectors of all kinds, in robots, in UAVs, in automated language translators, and so on. Electronics are at the heart of the netcentric warfare concept and are already key to current battle command technology. Improvements in electronics, especially those promised by the contributions that nanotechnology can make to computing, will lead to improved performance of these systems that will, in turn, address many of the gaps identified in SRO(I) and in this report.

For fifty years the technology for electronic circuits has been driven by demands for ever smaller, faster, cheaper circuits with more capacity for calculations and for memory storage. Devices that began using electron tubes in very large arrays have evolved into integrated circuits on semiconductor chips with critical dimensions currently in the upper nanometer range and still going down. Moore’s Law (a doubling of the number of transistors on a single chip will occur every 18 months continues to accurately describe the rate of progress. In fact one futurist asserts that this growth rate, itself an exponential, increases exponentially as well.[34] Current concepts in the laboratory promise to provide even more advances that should, in turn, facilitate the development of more capable electronic devices. First we turn to the new concepts and then forecast some examples of new or extended capabilities in devices that should ensue.

A recent development in making microchips is the multi-core chip, wherein more than one microprocessor is placed on a single chip. Since part of the heat load arises from resistance heating of the copper connections between chips, multi-core technology reduces the heat generated by the processors. Chips with two or four “cores” are already available in the personal computer market. Intel has designed a chip with 80 cores that holds 100 million transistors on a chip 15x15mm in area, and which can do 1 teraflops while generating only 65 watts of heat.

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[34] Ray Kurzweil, email to authors, 15 January 2004; also see “Singularity: Ubiquity Interviews Ray Kurzweil,” *Association for Computer Memory*, available at <http://www.acm.org/ubiquity/interviews/v7i01_kurzweil.html>.

However the new chip will require new memory concepts and new software for operating systems and the like. Intel projects availability in about five years.[35]

Work on integrated circuits on silicon and gallium arsenide chips, the current workhorses for most electronic devices, will continue in the chase for ever-smaller and more capable devices. Progress seems to lead inexorably to the use of nanotechnology. Chip design is now at the sub-micron scale or even at the upper reaches of the nanometer (10^{-9} meters) region. Challenging barriers remain to be overcome, but nanotechnology offers great promise.

Chips today are typically created with photolithography, a process that creates a pattern on a semiconductor surface by shining light through a mask, thereby activating a previously applied coating. A pattern is then etched on the semiconductor metal substrate. In recent years another approach has been studied wherein the pattern is built up from individual atoms, or clusters of atoms, placed on the substrate. This requires the ability to put these nano-sized entities wherever one wishes.[36] An early if not the first demonstration of moving atoms around on a surface was done at the IBM Almaden Laboratory by depositing a few xenon atoms on a nickel surface and then dragging them into position using the tip of the probe of a scanning tunneling microscope.[37] It is now possible in this way to write on a substrate by positioning individual atoms.

The field of nanotechnology has blossomed. Articles on carbon nano-tubes appear from laboratories around the world. The discovery of new molecular forms of (self-assembling) carbon began the “Buckyball,” a structure with 60 or more carbon atoms in a spherical shape reminiscent of the shape of the domes created by Buckminster Fuller. This soon led to other shapes such as hollow cylinder tubes, or nano-tubes, produced not just from pure carbon but also from other carbon-based chemicals. These nano-sized tubules have many new properties; e.g., high electrical and thermal conductivity. They are now being manipulated to produce a variety of effects. One such is a photoconductive nano-tube that is an insulator in the dark and a conductor of current in the light.[38] Another possible application is to use nano-tubes as heat pipes to conduct heat away from semiconductor chips; heat management is a critical barrier to developing smaller chips. As work continues one expects more useful developments to emerge.

As the dimensions of the features on semiconductor chips approach the atomic scale, quantum effects become crucial to chip design. Devices can be made based on these effects rather than on simple on/off electrical switches as in the usual semiconductor devices. Two such phenomena are quantum wells and quantum-based computer elements.

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[35] Tom Krazit, “Intel Shows Off 80-Core Processor,” *CNET News.com*, available at <http://articles.techrepublic.com.com/2100-10877_11-6158181.html>; see also *Defense Science Board Task Force Report on High Performance Microchip Supply,* Office of the Undersecretary of Defense for Acquisition, Technology, and Logistics. Washington, DC, February, 2005.

[36] Working at the atomic scale was proposed in a classic lecture by Richard Feynman in 1959 at the annual meeting of the American Physical Society at the California Institute of Technology and later published by Cal Tech. The transcript of the lecture, titled, “There’s Plenty of Room at the Bottom: An Invitation to Enter a New Field of Physics,” is available at <http://www.zyvex.com/nanotech/feynman.html>.

[37] For images, see “Scanning Tunneling Microscopy,” *IBM Corporation*, available at <http://www.almaden.ibm.com/vis/stm/atomo.html; D Eigler and E K Schweizer, “Positioning single atoms with a scanning tunneling microscope,” *Nature,* 344, 524 (1990)

[38] Mitch Jacoby, “Nanotube Photoconductors,” *Chemical & Engineering News*, 18 December, 2006, available at <http://pubs.acs.org/cen/news/84/i51/8451notw6.html>.

Quantum wells are based on the quantum effects, which can be produced by constraining electron behavior in one-, two-, or three dimensions. The electrons are confined in a potential energy well that may be bounded so as to create a two-dimensional sheet (quantum well), a narrow channel (quantum wire) or on all sides (quantum dot). This confinement of the electrons makes the device more capable. The quantum well infrared detector capable of providing images at room temperature is one application.[39]

Nanotechnology and quantum effects also enable alternatives to traditional semiconductors. For an electric switch in silicon there are just two states; a switch "on" represents a 1, switch "off" represents a 0. Coupling strings of these binary switches (or transistors) produces numbers that can be manipulated in the computer. The binary element is known as a bit. For the analogous quantum device based on, for example, flipping electron spins (spin up and spin down) in an atom, the individual functions are known as qubits. A phenomenon in quantum mechanics called superposition means that all possible values of the qubit are present at once. Thus the qubit for spin up and spin down contains both at once as compared to the bits where each value must be explicitly represented. Thus coupling qubits produces a greater ability to represent values than the ordinary on-off bits. The capability of a computer based on qubits would increase exponentially with the number of qubits.

Consider a classical supercomputer with petaflop (10^{15} floating point operations per second) capacity. Such a computer is now in the design stage and will contain hundreds of thousands of microprocessors (each of which contains many thousands or even millions of transistors). A quantum computer with just a 1000 qubits would be an approximate match. The speed up varies depending on the application. For data searching the speed-up might go as the square root of the size. For factoring large numbers the speed-up is exponential. For encryption at 128 bits, quantum computer could break the encryption in minutes; practically speaking, a classical machine could not solve the problem.[40]

The result would be a machine vastly more capable than a machine based on conventional microprocessors. Although a few laboratory devices based on qubits have been made that can perform elementary calculations, construction of a practical computer using tens of qubits is likely 5-10 years away[41] and commercial machines in fifteen or twenty years—the supercomputers of tomorrow. However, useful things can be done already with just a few qubits.

Other innovative design techniques will also enhance electronics capabilities in the coming years. Research on using nanotechnology to make flexible electronic circuits is underway.[42] The circuit is made of by depositing nano-particles on a substrate and then lifting the circuit off intact using a film of a soft polymer and transferring the circuit onto a flexible substrate. They call this stamping. The result is the possibility of producing circuits in a number of configurations for use,

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[39] WD Nothwang, MW Cole, and A Goldberg, "Cutting Edge Infrared Detector Materials Enhance Army's Night Vision and Targeting Capabilities," *AMPTIAC Quarterly,* Vol 8, Number 4, 2004, 111.
[40] T.R. Gouvindan, interview with authors, Army Research Office, Raleigh-Durham, NC, 22 February 2007 .
[41] Gouvindan, ARO.
[42] J.A. Rogers et al, "Heterogeneous Three-Dimensional Electronics by Use of Printed Semiconductor Nanomaterials," *Science,* 14 March 2006.

for example, in applying them to the skin for purposes of medical monitoring. Here, progress has been made at the Army Research Office (ARO)-sponsored Institute for Soldier Nanotechnology (ISN), a research effort led by the Massachusetts Institute of Technology in collaboration with Army laboratories, industry, and other universities, and other places on the synthesis of a conducting polymer.

Even Deoxyribonucleic acid (DNA) can be used to make electronic devices. DNA is a polyelectrolyte with a high molecular weight. It ionizes in water to produce a chain of charged sites. Recently experiments have shown that when electrodes are attached to both ends of a polymer such as DNA, current is conducted over only a certain voltage range. Thus DNA is a semiconductor. The chemical attachments to DNA—combinations of the four bases that constitute the genetic code—can be arranged in many different ways. There are several known conformations of DNA including single strands that may be coiled or extended, double strands (the usual conformation in living cells), triple strands, and closed circular structures. Another interesting property is the ability of DNA to self-assemble. This variability offers many possibilities for making electrical devices. One can envision scientists and engineers using these properties to build many different kinds of circuits on substrates.[43] It is likely that practical devices built up of such molecules will not be practical for at least a decade or two.

Sensors

All this improved computing power can and will serve many purposes. Of particular interest are the potential uses for sensors. For example sensors are components of UAVs, devices that are playing important roles in S&R operations in Iraq and Afghanistan. More sensitive sensors can detect explosives in vehicles or on persons before the warfighter comes in harm's way. Improved sensors on more capable UAVs and robots will enable soldiers to scout dangerous situations while remaining a safe distance away. Reliable detection of toxins that may be released on the battlefield will ensure that soldiers take the necessary precautions. Physiologic sensors can measure the individual soldier's medical status and relay it to the combat medic. All these applications and more can make important contributions to the Army's S&R capabilities.

Electronic sensors collect data and relay it to the user where the data are processed into useful information. Some uses require continual collection of data and frequent or continual transmission of the data to another site. As the memories and processors at the sensor become more powerful, data reduction and interpretation can be done there and the only the results of interest transmitted to the user, saving valuable communications bandwidth for other purposes.

Persistent surveillance is one such application. Imaging sensors on manned or unmanned ground and air vehicles will, in the future, be able to collect a steady stream of digital images of a specified region, filter and store the images in memory, analyze them for particular features or changes in features, condense the information and communicate the result to the user. The same will be the case for automatic target recognition—rather than sending down all the information, only the coordinates and identification of the target will need to be transmitted. Further, in some applications there are or will be ensembles of distributed sensors. The new capabilities should enable these sensors to communicate with each other to fuse their data to arrive at a composite

[43] V. Bhalla et al, "DNA Electronics," *European Molecular Biology Organization Reports,* Volume 4, No.5, 2003.

view. Combined with the data fusion that will occur on each sensor, the result should be reasonably accurate representations of the real world.

Some developments in radar and laser detection and ranging (ladar) will include the ability to operate to carry out different operations at the same time (multi-function). Radar and ladar devices will become much smaller and lighter, enabling application where one can approach a target very closely. One possibility is in producing images good enough to be used in biometrics for identifying individuals based on radar/ladar scans of their features from handheld device. Such devices may become sensitive enough to locate trip wires used to set off explosives. One desired application for radar is to see through the walls of buildings where opposing forces may be hiding. This application has been confounded by the many different materials that may be encountered. (However, see the advances in high-energy pulsed lasers for an alternative.) More research is needed in this area and it may be five years or more before an acceptable solution can be implemented.[44]

Infrared (IR) imagers have many military applications. Work is currently underway in the laboratory to make multi-spectral focal plane arrays (FPAs) so that data can be obtained at two or more wavelengths at once and the data fused. (The Stinger missile's IR detector operates at two frequencies now but is not an imaging FPA.) In other IR work, high-resolution IR imagers have been operated at cryogenic temperatures to enhance the signal to noise ratio. In recent years IR imagers that operate at room temperature have been developed at some sacrifice in resolution. It is reasonable to expect that the desired resolution at ambient temperatures will be possible in the near to mid future. The detector elements will likely not be based on the mercury-cadmium/tellurium devices that now predominate. New imagers based on quantum well infrared photodetectors (QWIPs) are one class of candidates. Another class is based on bolometers as detectors that sense temperature increases due to the impact of incoming radiation. The increase in temperature of the sensor is then measured by changes in the resistance of very sensitive circuits.

Sensors technology for defensive systems is making great strides. In early work related to active protection systems, a very broad band (noisy) outgoing signal is used in a wide sweep to pick up the reflection from an incoming round (e.g., a rocket-propelled grenade). By repeating the process several times, it is possible to produce a narrow coherent beam with azimuth and elevation that can be used to fire an intercepting munition at the threat.[45] Further, remote sensing of electronic devices by analysis of reflected radar signals is now possible in the laboratory. After pinpointing the source it should be possible to interfere with its operation.[46]

Defensive sensor systems are also being developed to cope with indirect fire. The Ancile system[47] couples current counter-mortar radars with positioning and warning devices worn by individuals. The system detects that enemy fires are inbound and the checks to see if positioning devices worn by friendly forces indicate they are in the projected impact area. If the system calculates soldiers are in danger it signals them and indicates a direction to move away from the

[44] J. Pellegrino, interview at ARL, Adelphi, MD, 13 Nov 2006.
[45] D. Palmer, technical discussion at ARO, Research Triangle Park, NC, 22 Feb 2007.
[46] Palmer technical discussion.
[47] "The Ancile System", http://www.ancile.net, accessed 5 Jul 2007.

impact area. Several difficulties can be imagined. Warning time would be very short. Enemy mortar fires are often imprecise multiple round attacks. Troops training for indirect fire attacks traditionally have been instructed to seek immediate shelter from incoming rounds; Ancile alerts troops to an impending danger but does not direct them to a safe area. The system should not be discounted but needs a genuine soldier evaluation prior to full funding.

A recent development in chemical sensors is one in which fluorescence is either reduced or increased by the adsorption of explosive particles. The current model (FIDO) works only on TNT since the interaction with the fluorescent material is very specific.[48] Chemists will certainly be able to develop other fluorescent dyes for other explosive molecules. There is important work being done on this subject at the Army's Institute for Collaborative Biotechnology (ICB). ICB, an ARO-sponsored effort led by the University of California Santa Barbara and that includes the Army laboratories, industry, and other universities, tries to understand unique features found in nature and biology that exhibit performance characteristics of interest to the Army and translate these features into useful capabilities. ICB's research in this particular area includes making molecular identification using a surface-enhanced spectrographic technique known as SERS to increase signal response. The challenge has been to develop nanometer-scale substrates that would become SERS-activated and show up as electromagnetic hot spots that can concentrate the incident laser radiation. One such technique to form the substrate involves silver film and silver nano-particles that, in the presence of the target explosive or bioagent molecule, will self-assemble to form the hot spot indicative of a stray SERS signature. This work is in very early stages of research.

Quantum dots are another exciting nanotechnology area. These are a unique type of semiconductor that range in size from two to ten nanometers and act as sensors. By coating crystallized semiconductor nano-particles with biological materials designed to interact with specific biological entities, very specific detection can be achieved. Quantum dots produce very well-characterized emission spectra; the effect of the reaction of the coating material with the biologics of interest is expressed in a modification of these emissions. The response is said to be very sensitive even to small concentrations.[49] Also, it is possible to nano-engineer the dots so that they respond to a wide range of wavelengths, avoiding the need to tailor the detector to specific wavelength IR windows. The ISN has made significant progress on quantum dots. ISN accomplishments to date include the continuous synthesis of complex nanoparticle quantum dot structures (rods, spheres, etc.) and the preparation of hybrid organic/quantum dot or metal oxide/quantum dot thin films. ISN hopes to use these dots to assemble lightweight, flexible sensor arrays that would form an integral part of a new battlesuit for soldiers. Again, this work is at a very early stage.

This research could also apply to sensing biological agents. Sensors for bio-agents are currently in demand against the threat of biological attack both in the military and on the home front. There is much research underway. There are two kinds of problems: remote sensing in the atmosphere of agents dispersed from aircraft, and sensing in more concentrated form in samples

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[48] S. Lee, technical discussion at ARO, Research Triangle Park, NC, 22 Feb 2007.

[49] M. Stone, "Applications of Biomimetics," *The Bridge,* The National Academy of Engineering, Winter 2006, 21 and references therein. Palmer interview; J D Joannopoulos, "ISN Overview Briefing, Cambridge, MA, 26 March 2007.

taken at a particular point on the ground. The measuring problems are different. For sensing where one is looking for clouds of released agents in the atmosphere, the sensor must have extraordinary sensitivity and must operate on reflected signals from the agent in response to an interrogating beam. In clouds of aerosols of the agent there will always be dust particles; on the battlefield there will also be smoke and particles from explosives. The analytical challenge is severe. The Army is now working on Doppler ladar to track and identify the aerosols at 10km stand-off in a small bread-box sized package

A somewhat easier problem is analysis of samples taken at a point source using, for example, a filter of a stream of ambient air over a period of time. There are techniques for concentrating the biologic agent by active transport in solution across a membrane against concentration gradients.[50] For the case of solid samples, the captured agent on the filter may be looked at with a variety of instruments such as gas chromatography/mass spectrometry (GC/MS). We have mentioned above the possibility of using sensors based on quantum dots coated with special receptors for the biological agent of interest. There will be interference from other benign chemicals in the sample; these have to be anticipated and corrected for in the instruments for both point source and remote measurements. Relatively small packages of GC/MS instrumentation have already been developed; the point source problem appears to be on the way to being solved.

There is work on biosensors using antibody-based DNA in which DNA is tethered to an electrode. The DNA extracted from the unknown sample may couple to the tethered DNA depending on its base composition. The absorption may then affect a marker such as a fluorescent dye. This could also be sensed by having the tether to a microelectromechnical systems (MEMS) cantilever, thereby affecting the lever's resonant frequency.[51] (In the MEMS concept a tiny lever is carved out of the substrate—for example, silicon—by lithography. The lever is so sensitive that the absorption of a chemical will change its mass sufficiently to change its resonance signal.) These efforts are still in the laboratory.

Recent work on high energy lasers has produced several advances of interest. Using extremely narrow pulses (attosecond widths, 10^{-18} secs) it may well be possible to penetrate almost every material. These lasers can be used to create positrons for electron spectroscopy, and harmonics in the ultraviolet. This could lead to a see-through-the-wall imagery system for use by the Army.[52] Researchers are working on high-energy fiber-optic lasers that may replace the dye lasers now being studied for directed energy weapons.[53]

Studies on the wave properties of atoms have made possible a gyroscope 11 orders of magnitude more sensitive than the current laser ring gyros. These could sense tiny changes in the earth's gravitational pull at a given location, and are so sensitive that they could detect voids underground such as tunnels.

[50] D. Stepp, technical discussion at ARO, Research Triangle Park, NC, 22 Feb 2007.
[51] R. Kohuska, technical discussion at ARO, Research Triangle Park, NC, 22 Feb 2007.
[52] D. Hammond, technical discussion at ARO, Research Triangle Park, NC, 22 Feb 2007.
[53] Hammond technical discussion; V.M. Shalaev, "Optical Negative-Index Metamaterials," *Nature/Photonics,* January 2007.

Power Sources for the Individual Soldier

All electronic devices require a source of electric power. Presently the dismounted soldier must carry replacement batteries for such critical equipment as radios, adding to his already heavy combat load. This will be reduced in several ways: the large variety of battery designs should, and almost certainly will, be reduced so that fewer battery models would be needed to cover all exigencies, the power demand of the electronics will be reduced by more careful design, and the source of power (now batteries) will either be substantially upgraded or, more likely, replaced with more efficient and effective devices.

The Army states that it needs an average of 10 watts of power to supply the individual soldier, with peak demand up to 30 watts. The best batteries now in use are lithium-based. These now have a capacity of 150 watt-hours; it is predicted that these may go as high as 500 watt-hours.

Compared to the energy density in carbon-based fuels (gasoline or diesel fuel) batteries are relatively poor power sources. Petroleum (e.g., gasoline), for instance, contains about 13 kilowatts per gram (kW/g) while lithium-ion produces about 0.2 kW/g.[54] The energy density of hydrogen, however, is 38 kW/g, far better than either of these. This leads us to the promise of hydrogen-based fuel cells.

A fuel cell converts chemical energy into electrical energy. Typically a source of oxygen and a source of hydrogen are fed to two electrodes. The ensuing reaction produces water and an electric current. Using hydrogen and oxygen gases as feeds would produce the most current per gram; using air for oxygen and methanol instead of hydrogen would produce less energy but still a great deal more than batteries. These materials would also be less expensive and safer. The organic fuel can be reformed catalytically within in the cell to produce hydrogen, or in the design called direct methanol fuel cell it is claimed there is no need for an internal catalyst. Fuel cells do not store energy but rather produce it on demand. Thus there is no need for recharging. The soldier would need to carry a pouch with half a pint or so of methanol as the energy source.[55] The experts believe methanol fuel cells will be available in limited quantities in about five years and that costs will come down as the number of units produced.[56]

Lithium-ion batteries, used today in cell phones and other small electronic devices are now beginning to appear in portable power tools, replacing the less capable nickel/cadmium batteries. This change is based on new lithium combinations that may, it is claimed, be useful in hybrid vehicles as well.

Other sources of power on the battlefield include solar devices for the individual soldier. The efficiency of photovoltaic cells continues to improve. ICB, recognizing that plants are incredibly

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54 "What's the Best Battery?," *Cadex Electronics Inc*., available at <http://www.batteryuniversity.com/partone-3.html>; "Batteries," *The Energy Advocate*, available at <http://www.energyadvocate.com/batts.htm>; and "Heat Content of Fuels, *The Energy Advocate*, available at <http://www.energyadvocate.com/fuels.htm>.

55 "First Light-Weight Soldier Power/Fuel Cell Delivered to German Army,"Army-Technology.com 1 December, 2006, available at <http://www.army-technology.com/contractors/electrical/SFC/press1.html>.

56 "First Light-Weight Soldier Power/Fuel Cell Delivered to German Army,"Army-Technology.com 1 December, 2006, available at <http://www.army-technology.com/contractors/electrical/SFC/press1.html>.

efficient at the conversion of sunlight into energy for their daily lives, is taking lessons learned from sponges to assemble new photovoltaic devices.

A research effort at the ISN is investigating biologically based electrodes, which enable the development of thin film batteries. Such batteries can be integrated into textiles such as may be used for the battle uniform. ISN is using viruses to synthesize and assemble nanowires of cobalt oxide electrodes for use in lithium ion batteries. Low level radioactive sources can also provide energy. It may even be possible to generate sufficient power for the soldier's needs from body heat.[57] This will require a significant lowering in power demand.

Basic Research in Advanced Materials

New materials have provided for significant capabilities advances for many fielded weapons systems; e.g., composite armor packages for the Abrams tank or well-protected cockpits for Apache pilots. To realize future capabilities advances for S&R operations and, more generally, candidate materials for components and sub-systems must be understood from a behavioral and processing standpoint so that informed decisions can be made about their application. Characterizing material behavior and optimizing processing parameters has to date been largely empirical, with knowledge gained through painstaking experimentation. There are signs that this is about to change. A Strategic Technologies for the Army (STAR) Study in the early 1990s offered the opinion that "the ability to predict in detail the collective effect of atomic interaction in macroscopic properties of materials will revolutionize the way material scientists design and tailor advanced materials."[58] This "materials by design" revolution is beginning.

Key to this new approach are computational capabilities that permit significantly improved understanding of electronic and molecular structures, phase stability, processing parameters, and the resulting physical and mechanical properties. Computing modeling in science and engineering has made great strides. For example, the Army High Performance Computing Research Center capabilities include cluster computing systems and parallel high performance computers with vector processors and advanced software and hardware features. With such capabilities, materials can be designed building from the "ground up", i.e., from the base components - atoms, molecules, and micro crystallites – in such a way as to optimize the desired properties. This approach should afford materials to meet important Army requirements such as reduced weight and better ballistic protection. Some discussion of advanced materials development involving elements of the above computational approach are worthy of note.

This computational capability has enabled important advances in Army materials work. These advances include exterior ballistic computations that address the effects of high speed turbulent flow; interior ballistic computations that study high-speed/high-pressure reacting fluid flows, and modeling that characterizes behind-armor debris that is formed after a projectile penetrates a target. To cite one important example, materials by design were used to improve the performance in kinetic energy projectiles in the mid-1990s. Analytic techniques that provided failure mode models at the differently oriented ply or laminate levels led to purpose-designed composite

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[57] Palmer technical discussion.

[58] *STAR 21, Strategic Technologies for the Army of the Twenty-First Century, Technology Forecast Assessments*, Board on Army Science and Technology, National Research Council (Washington, DC: National Academy Press, 1993).

materials. These materials made it possible to reduce the weight of the long rod penetrator sabot, which translated into increased muzzle energy for the projectile, thus improving ballistic penetrator performance.

Further strides in material science have been made at the nanometer scale level, some advances in which field were discussed in the Electronics section. At this scale, electronic structures and quantum mechanical effects are important and begin to shed light on the physical and mechanical behavior of the bulk material. This new and exciting area of atomic scale materials science has become known as nanotechnology (see p51).

Advances in nanotechnology have resulted in a much deeper understanding of the properties of traditional engineering materials. Researchers at Northwestern University have utilized quantum theory and advanced computing power to gain new insights about the effects of impurities such as phosphorus on steel embrittlement. They have shown that the phosphorous bonding energy in the grain boundary is less than it is in iron resulting in grain boundary embrittlement. The goal is to utilize such fundamental models together with appropriate databases to effect computational design of materials.

Complementing the modeling from first principles using the more powerful computational capability is the emergence of imaging tools. These tools help scientists to manipulate and characterize materials at the atomic scale. Advances in electron microscopy and neutron probes are enhancing this capability.

Several important applications of nanotechnology have been mentioned in the foregoing sections —quantum dot-based sensors, autonomous drug delivery, conducting polymers. ISN seeks to combine these advances with other nanotechnology developments to create a 21st century battlesuit. In addition to having integrated sensors, soldier-monitoring, and communications devices, it could provide excellent ballistic protection at light weight. Newly developed synthesis techniques for strong, energy absorbing polymers, such as the iptycene family, could lead to applications for molecular architectures consisting of "chain mail" or stiffened micro-truss polymeric structures. This type of architecture provides the basis for lightweight, breathable, efficient polymers needed for blast and body armor for the soldier.

Such a battlesuit could also include biologically inspired camouflage. ICB is developing a detailed molecular understanding of elaborate and rapidly changing camouflage and environmental mimicry employed by cephalopods (squid, octopus, and cuttlefish). These organisms use a variety of mechanisms of adaptive coloration in combination with each other, rapidly, and controlled by the brain—hence the changes in outer coloration are termed by scientists a "rapid, neurally-controlled polymorphism." These mechanisms include: general background resemblance, concealment of shadows, disruptive coloration, and so on.. Most animals use only one form but cephalopods use all of them. Vastly more elaborate than current military concealment techniques, what ICB learns from squid hiding from predators could have applications in the Army and beyond.

Robotic Systems

The concept of machines replacing humans in a variety of tasks has a long history—back into antiquity. Leonardo da Vinci designed automata but didn't try to build them. The term "robot" was first used by writer Karl Capek in a play written in 1920. The technology for robots evolved slowly until the electronics and computer revolutions in the latter half of the 20th century. With this technology industrial robots were developed with fixed bases and moveable arms. The arms were taught by moving them through the desired actions and putting the information into the robot's on-board control computer. They performed such tasks as pick and place parts, painting, and welding. Some had limited vision capabilities; enough so they could focus on the job at hand. They were not autonomous. Other robots had limited mobility—they could travel predetermined paths to move materials about the factory or within office buildings. In the 1970s and 1980s the Japanese developed robotic nurses to handle such tasks as moving patients. More recently a market has developed for robots that perform domestic tasks, such as cleaning homes[59] or mowing lawns.[60]

New developments in robotics—in particular UGVs and UAVs—are addressing some of the S&R capability gaps described in the foregoing chapters. Today, for example, UGVs are handling IEDs and exploring caves. UAVs are not only performing surveillance functions but are also serving in some cases as weapons platforms. We believe that robots will assume more functions, especially in areas of high hazard. Eventually robots will be equal to or better than humans in many ways. One day teams of robots coordinated on the ground and in the air will likely replace soldiers who would otherwise be in harm's way. Such a development will mean rewriting much of the Army's training and doctrine. We review here current programs as well as predictions for the future.

The use of robotic systems in warfare is not new, with origins going as far back as World War I when the Germans were the first to produce and deploy remote-controlled minefield breaching vehicles.[61] Today, the U.S. military has over 4,000 robotic ground systems, with most of them serving in explosives ordnance disposal (EOD)-related jobs in Iraq and Afghanistan. [62] The number of UAV systems is just as impressive. The Army's Future Combat Systems program relies heavily on developing robots, both on the ground and in the air. There are four unmanned air vehicles and six unmanned ground vehicles (depending on how one counts variants). The small-unit ground vehicle is designed for handling unexploded ordnance and exploring hard-to-access or very dangerous spaces. There is a reconnaissance and surveillance scout vehicle as well as an armed version. And there is an unmanned logistics vehicle to haul materiel and supplies alongside the soldier. Unmanned vehicles do not need a crew compartment or the armor required for manned vehicles; they will therefore weigh less for a given capability. They can be provided with a number of different sensor systems, beyond those available to the soldier.

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[59] "Clearing Robots," *iRobot*, available at <http://www.irobot.com/sp.cfm?pageid=95>.
[60] "Robotic Lawnmowers," *ConsumerSearch*, available at <http://www.consumersearch.com/www/lawn_and_garden/robotic-lawn-mowers/review.html>.
[61] Major William C. Schneck, "The Origin of Military Mines, Part II," *Engineer Bulletin*, November 1998, available at <http://www.fas.org/man/dod-101/sys/land/docs/981100-schneck.htm>.
[62] Ellen M. Purdy, "Joint Ground Robotics Enterprise Overview," presentation to National Defense Industrial Association (NDIA) Robotics Division, Arlington, VA, 2 November 2006.

These unmanned vehicles have varying degrees of independence from the soldier. (There will always be a man in the loop at some level.) As shown in Figures 3 and 4,[63] evolution begins with direct manual control through varying degrees of remoteness of the operator and the level of his interaction with the robot. At the lowest level the operator stands close to the robot and directs the basic movements; at the highest or autonomous level, the operator simply gives the robot a task much as he would to a soldier. Current work is on semi-autonomous robots; the end objective is full autonomy. For example, the ability of robotic vehicles to follow way points over large distances was exhibited in DARPA's recent Grand Challenge where semi-autonomous robots followed way points in the Mojave Desert along a route of 132.2 miles.

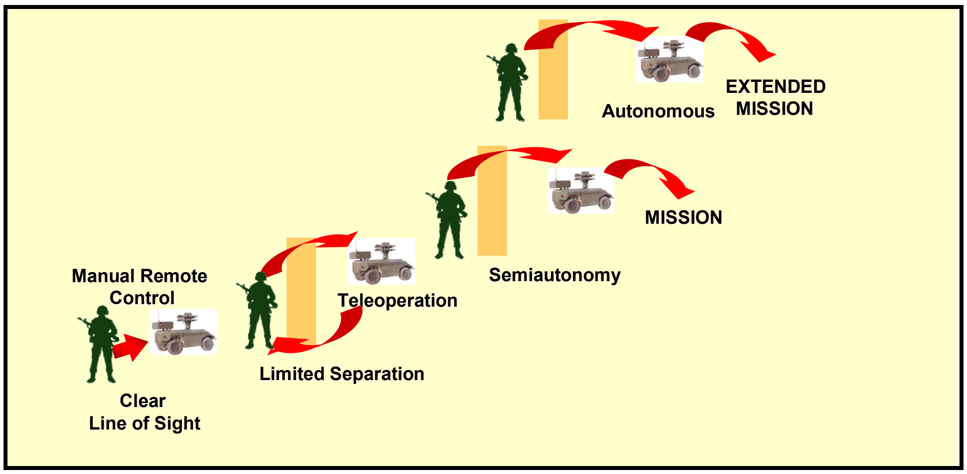

Figure 3. Evolution in UGV Systems

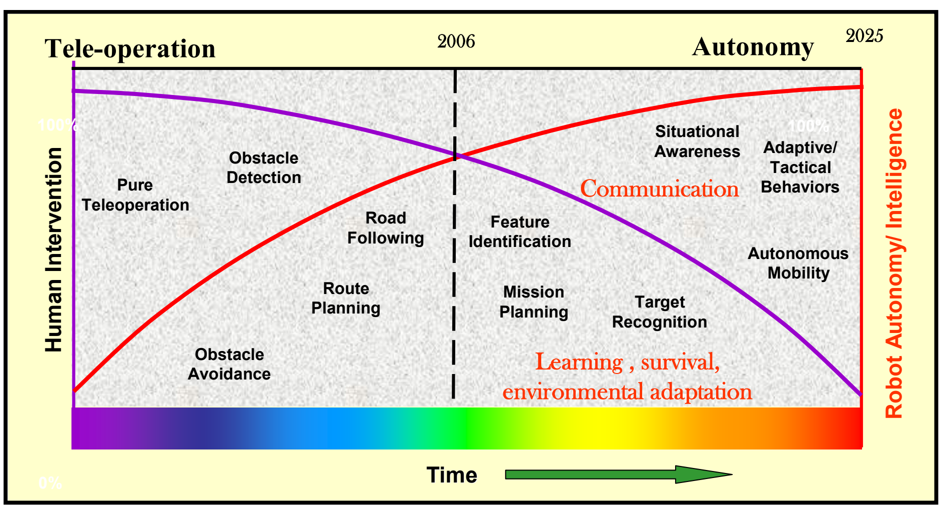

Figure 4. Evolution in UGV systems

The current UGVs can operate semi-autonomously in a "static" mode, i.e. where changes in the environment are relatively slow. They should be able to operate in a "dynamic" mode in traffic

[63] Millard F. Rose, "A Perspective on Unmanned Ground Vehicles for Military Applications," *Annual International Test and Evaluation Association Technology Review*, ITEA Conference Proceedings, 9 August, 2006; National Research Council of the National Academies, *Technology Development for Army Unmanned Ground Vehicles* (Washington, DC: National Academy Press, 2002).

by 2009 or 2010; i.e., have the capability to react to sudden changes such as a pedestrian jumping off the sidewalk or a vehicle entering from a blind intersection.[64] Figure 5 reflects other core robotic competencies and their accompanying readiness timelines.[65]

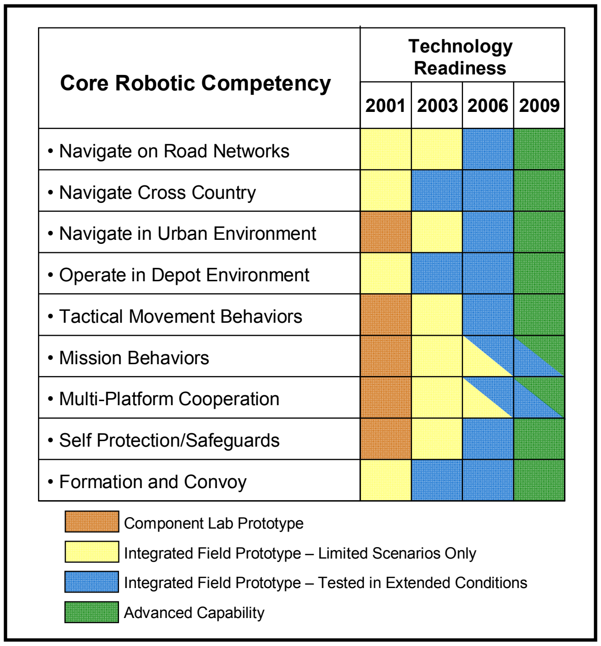

Figure 5. Projections of robot capability for various component technologies.

Robot operation consists of sensing, analysis, planning, and execution. For example, in navigation the robot is given a plan of action and a database (maps etc). The sensor tells it where it is and compares that to the model of the world it has in its memory; i.e., the planned position for that time. This requires detail digital terrain mapping, a tedious, high-cost space-based process of database generation. Mapping all potential areas of robot employment, especially as the terrain changes due to the disruptions of combat, is a significant challenge that calls for technology to speed the mapping process and lower the mapping cost. Currently, the Army must work with the National Geospatial-Intelligence Agency to set tough priorities for digital mapping requests.

The robot's computer then prepares a series of instructions to keep it on its planned route. Major technical challenges relate primarily to the capabilities of the perception systems and of data fusion (as discussed earlier in this chapter). Currently perception is done by a combination of sensors—ladar for detection and ranging and electro-optical systems (television, IR) for imaging. The current generation of ladar has a resolution of about 0.2 degrees per pixel versus the human eye's resolution of 0.01 deg/pixel. Ladar can define a range with an error of +/- two centimeters at 20 meters. The laser pulse rate is limiting at 10,000 per second. The ladar is now able to classify objects but not able to identify them; i.e., an object may look like a vehicle but it cannot tell what kind. The ARL Collaborative Technology Alliance is working to improve on this.[66] A very recent development is an experimental ladar imaging scheme that resembles the human eye's fovea wherein there are more pixels in the center than at the periphery. The device can scan so as to place objects of interest in the center of the field of vision. Ultimately robots may also be guided by and collect data from radar, infrared imagers, and acoustic sensors, the data from which the robot could fuse. [67]

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[64] James S. Albus, interview with authors, National Institute of Standards and Technology (NIST), Gaithersburg, MD, 21 March 2007.
[65] Ellen M. Purdy, "Joint Ground Robotics Enterprise Overview," presentation to National Defense Industrial Association (NDIA) Robotics Division, Arlington, VA, 2 November 2006.
[66] Jonathan Bornstein, interview with authors, Robotics Program Office, Weapons and Materials Research Directorate, Aberdeen Proving Ground (APG), Aberdeen, MD, 12 April, 2007.
[67] Albus interview; Bornstein interview.

Fully autonomous capability for robotic systems will require computing capability at a level approaching that of the human brain. Futurist Ray Kurzweil has asserted that the computer and the brain will be equal in capability by 2025 or sooner, and that eventually we will have desktop machines competitive with the human brain.[68] One estimate is that the brain has about 10^{13} functioning elements.[69] This is 10 teraflops (10^{12} flops); a petaflops machine is now being designed (also see p48). About 10 percent of the brain is used in image processing; for most situations only a modest portion of the brain is called into play. Some believe that there is no inherent difference as between the computer and the brain for situations of interest to the military; that these will all be reduced to arithmetic calculations.[70] The brain will be slower in doing calculations; faster in other types of cognition.

To achieve, then, the maximum potential of robots, advances in science and engineering will be required. Understanding of brain functions and relating them to robot management functions will come from advances in neuroscience; managing swarms of robots will depend on advances in network science. These in turn will be enabled by more powerful research tools and the continuing evolution of solid state physics, optics, and computers.

ICB, with an eye toward complex networked systems such as those that future applications may call for, is working at networked biological systems and attempting to answer how birds flying in flocks communicate or how fish are able to stay in a perfect swarm formation. ICB researchers are drawing on studies of networks at all biological levels—internal networks of molecules within cells, cell-cell communication within the brain, the network of behaviors within an individual organism, and the networks formed by three-dimensional swarms of animals in varied environments. The ICB teams are reverse-engineering natural biological networks—made efficient by millions of years of evolutionary natural selection—and using this knowledge to improve or newly design human-created networks. For example, a good deal of this research has applicability to the Army's FCS. While the functions of the component systems of FCS are understood, it is far less clear how these components will efficiently and robustly work together when the network is "stressed" in the field. ICB scientists can already describe mathematically the behavior of a disrupted swarm of fish or birds. This approach may help with analyzing the behavior of battlefield networks.

The military will want to orchestrate groups of robots. This will require improved perception with a wide field of view. If the robots are built by different companies the Army will either have to require a single design of the software or, more likely, develop a neutral data interfaces. This has already been done in automated factories. As robots develop more human-like capabilities operation in groups will become easier. But it is probable that there will be soldiers alongside and a soldier overseeing the groups of robots. One can imagine the battle of the future conducted and supported by robotic systems with soldiers largely out of harms way. The rapidly increasing pace of technology suggests that by 2025 much of this vision will be reality.

[68] R. Kurzweil, *The Singularity Is Near: When Humans Transcend Biology*, Penguin, NYC, NY, 2006.
[69] Albus interview; James S. Albus and Alexander M. Meystel, *Engineering of Mind,* (New York: John Wiley & Sons, 2001).
[70] Albus interview.

Combat Casualty Care

In Iraq, 90 percent of the wounded survive compared to 76 percent in Vietnam. Faster evacuation, better body armor, improved medical techniques, and new field medical tools are among the reasons for the higher survival rate.[71] Much of this success derives from improved combat casualty care—care that differs very little in stabilization and reconstruction operations from that on classic battlefields. Despite the progress, however, there is still room for improvement. The Army continues to seek further reductions in the mortality rate through research and development and through improved training of soldiers and medics. The research is carried out largely by the Army Medical Research and Materiel Command (MRMC).[72] The biomedical program is divided for planning purposes into three components: infectious diseases, operational medicine, and combat casualty care. Some of the work is done jointly with other Army entities and with the other Services; advanced development is often funded and conducted by partners in industry.

The discussion in this section is focused on treatment of battlefield casualties. The medics talk of the "Golden Hour." If adequate medical care can be provided within the first hour after an injury the odds of survival improve markedly. Evacuation is done as quickly as possible, something on which the Army has made good progress. The top priorities are to provide immediate care to control bleeding and attendant shock, avoid hypothermia, treat head injuries and manage pain.

- *Controlling bleeding.* The tourniquet is one of the oldest devices for stopping bleeding in the extremities. Until the beginning of the Iraqi conflict, soldiers made tourniquets from cravats they carried for a variety of purposes. Today's soldiers carry their own specially designed tourniquets. The new tourniquets have a broader pressure area than earlier ones, are tightened by a "windlass-type" feature, and held in place by a catch. There is new doctrine to go with new equipment: (1) the tourniquet should be applied as soon as severe bleeding is observed and (2) it may be left tightened for up to four hours.[73]

  Applied pressure, usually by hand, is the main alternative to tourniquets. There are new pressure bandages treated with special blood clotting agents to control hemorrhage as well as disinfectants and agents to promote healing.

  There has been much attention to blood clotting agents, some of which have received extensive study and undergone field trials. Work has been done on dry agents in granules or in bandages that act to absorb fluids in the blood, leaving behind blood solids that act as a filter to concentrate the body's platelets and form blood clots. One such, known by the trade name HemCon™, is based on chitosan, a chemical that occurs naturally in shell

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[71] Major J.J. Dalle Lucca, "S&T Impact on Urban and Counter-Insurgency Operations," presentation at the Army Science Conference*,* Orlando, FL, December 2006.
[72] It is described in the Army Science & Technology Master Plan under the heading "Biomedical." *Army Science and Technology Master Plan, Vols. I and II,* Office of the Assistant Secretary for Acquisition, Logistics, and Technology, Headquarters, Department of the Army, July 2005.
[73] MAJ J.J. Dalle Lucca, interview with authors, Washington, DC, 24 January 2007; Dr J.F. Glenn, interview with authors, Ft. Detrick, MD, 13 February 2007; COL R.K.Martin, interview with authors, Ft. Detrick, MD, 13 April 2007; COL R. Vandre, interview with authors, Ft. Detrick, MD, 20 April 2007. MAJ Dalle Lucca is at the Walter Reed Army Research Institute; the others are at the Army Medical Research and Materiel Command, Ft Detrick, MD.

fish.[74] The effect is temporary—perhaps up to two hours. This product has been used in the field in Iraq and Afghanistan, and early results indicate that bandages with HemCon™ are useful and may be employed along with other, more traditional approaches especially when those approaches seem to be failing. These bandages are not, however, very effective for deep wounds and for cases where a limb has been blown off directly at the shoulder or hip. An alternative clotting agent may be useful in such circumstances: fibrin derived from animals. Fibrin is a naturally occurring substance that is central to the clotting mechanism. It could be applied either on a dressing or directly, for example, as foam. It has a lasting effect and is eventually, well after it fulfills it function, absorbed by the body. It is effective even on deep wounds. However, the use of fibrin has not yet been approved by the FDA (See below on High Frequency Focused Ultrasound).

The Army is also experimenting with a new blood clotting factor known as recombinant activated factor VII or, rVIIa.[75] rVIIa is approved for treating hemophilia (hemophiliacs are missing this protein) and is produced by Novonordic in Sweden. Emergency care specialists have tried rVIIa on severely wounded patients. It works very well even for such severe injuries as lacerated livers. One Army medical officer terms this "the most exciting thing going in hemostasis."[76] MRMC would like to see FDA approval of rVIIa for trauma; MRMC's Institute for Surgical Research is now doing research in support of Novonordic for FDA approval. It is accepted practice for physicians to use drugs approved by FDA for a specific circumstance to administer them in other situations (off-label application). However, a combat medic could only use rVIIa if approved for this specific use by FDA. Field surgeons are now using rVIIa in severe cases.

- Another approach to controlling bleeding in difficult locations is the use of *High Frequency Focused Ultrasound* or HIFU. Currently being tried in dealing with internal cancers, the technique would use scanning ultrasound to identify internal hemorrhage, Doppler velocimetry to locate the actual breeches in the vessels, and then use ultrasound from many sound transducers positioned on a wrap-around device and brought to focus on the bleeder. In this way the heat produced by the ultrasound is only enough to cauterize the tissue at the focus without damaging surrounding tissue.[77] There are of course many challenges in adapting this to combat casualty care on the battlefield; it seems unlikely that it would be used by the combat medics but might be at higher echelons.

Hemorrhagic shock often accompanies severe bleeding. In shock a series of changes occur as the body tries to deal with crisis. A function called "the complement system" contracts blood vessels near the site of the wound, slowing blood loss. In severe wounds, this system often over-compensates and causes further tissue damage. Current research seeks ways to control the complement system, most likely through additives to the blood

[74] Glenn, Martin, and Vandre interview.
[75] Glenn and Vandre interview.
[76] Vandre interview.
[77] "An Acoustic Hemostatis Device for Advanced Trauma Care." *The University of Washington Center for Industrial and Medical Ultrasound*, available at <cimu.apl.washington.edu/hemostat.html>.

expander, fluids added to maintain blood pressure.[78] Recent research also indicates, however, that it is possible to replace fluids too aggressively, thereby raising the blood pressure to the point where wound closing is reversed and more blood is forced out. Thus in treating serious blood loss one needs to maintain blood volume low enough to prevent this damage—just enough to maintain enough blood pressure to ensure consciousness but no more.[79]

Monitoring small, non-invasively obtained samples of body fluids can be a critical component of soldier survivability. Miniaturization achieved by the technology known as MEMS would allow the monitoring and response system to be integrated directly into a battlesuit. ISN is developing a MEMS-based drug delivery system for emergency administration of a vasoconstrictor to delay the onset of hemorrhagic shock. Underlying the release of the delivery is a miniaturized device capable of forming multiple thermally formed bubbles that release drugs much like the ink is released in a bubble jet printer.

Shock treatment also includes keeping the patient warm and, usually, elevating the feet or lowering the head to insure blood supply to the brain. The Army has introduced a system called the Hypothermia Prevention and Management Kit®. This encloses the patient in a cocoon-like wrapping that prevents heat loss without inhibiting treatment of the wound.

The Army is working on a light-weight autonomous critical care life support system in which priority treatments are administered via sensors and closed loop effectors such as ventilators and provision of fluid for resuscitation.[80]

Shock is primarily combated by replacing lost blood volume with plasma-like fluids. These contain sodium-, potassium- and calcium chlorides at levels normally found in blood plus a pH buffer to maintain blood acidity within the normal range. Some formulas contain a polymer to alter the physical properties; i.e., viscosity and osmotic pressure between the blood and the cells. One such in use on the battlefield is Hextend® fluid.[81]

Oftentimes when there is considerable dehydration, veins collapse and it is hard to successfully insert an IV needle. The combat medic doesn't usually have time to try to find a "good" vein. For giving medication such as analgesics, an alternative is to use a "through the skin" approach. There are some compounds that readily penetrate the skin and can carry medications dissolved therein. An example is the well-known dimethylsulfoxide (DMSO) now used by veterinarians. It gives a strong taste of hydrogen sulfide, even though it is topically administered, and thus is unpleasant; but it is very effective. Something similar would be very useful for the combat medic.

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[78] Major J.J. Dalle Lucca, "S&T Impact on Urban and Counter-Insurgency Operations," presentation at the Army Science Conference, Orlando, FL, December 2006.
[79] Dalle Lucca interview; Glenn, Martin, and Vandre interview.
[80] MAJ J.J. Dalle Lucca, "S&T Impact on Urban and Counter-Insurgency Operations", presentation at the Army Science Conference, Orlando, FL, December 2006.
[81] "Hextend- Product Approval Information," *U.S. Food and Drug Administration*, available at <www.fda.gov/cber/ndasum/hexbio033199S.htm>.

- *Brain injuries.* Injuries to the brain account for about 40 percent of battlefield deaths.[82] Blast injuries from IEDs are a particular concern in Iraq today. [83] Blast injuries come from first of all from direct overpressure from the explosion. The overpressure affects internal organs, principally the brain, through concussive forces. Further injuries come from blast fragments or bullets. A hemorrhage can be controlled by such as rVIIa. But there is tissue damage caused by inflammation around the wound site and this causes what is called non-convulsive seizures. Based on Army basic research, the firm Neuren has entered into a cooperative research and development agreement with MRMC to developing a drug to reduce or prevent the inflammation. Animal studies indicate that this drug is extremely promising.[84]

  Since the brain is locked in the brain case, swelling produces overall compression damage if left unattended. There are tools available in hospitals to assess intracranial pressure and bleeding, but a field test on a drop of blood to look for specific markers would be very useful. Such markers might be protein fragments produced by dying neurons. Research is in progress on this challenge but nothing has been fielded as yet.[85]

- *Medical Sensors.* On the battlefield of the future there will likely be fewer, but more effective soldiers. Thus in combat the medics will be some distance away from casualties. The Army needs physiologic sensors on each soldier such that they can send data to transmitters on the outside of the uniform that relay the information by radio to the medic. He can then make better judgments as to which soldiers require his immediate attention. NASA's astronauts have long been instrumented in a similar fashion. Such a measurement system is under development in the Army. In the Future Force Warrior program, which sought to design a new ensemble of uniform and devices, a large number of physiological properties will be measured on the individual soldier, including assessment of the soldier's overall readiness. Some of this is being evaluated in an Advanced Technology Demonstration at this writing. DARPA has been working on a pill that contains sensors and a transmitter to perform this function internally. One problem is that the pill is very large and difficult to swallow; another is that the pill will only reside in the body for about 24 hours. With advances in MEMS and nanotechnologies the first problem—size—will surely be overcome.

- *Pain Management.* Managing pain is a priority at all stages of combat medical care. Pain itself can aggravate the body's responses. Morphine intramuscular injections have been used in the past; it addresses the pain but affects the ability of the soldier to think and perform even if he is physically able. There is now the possibility of using an inhaler rather than an intramuscular injection. This still impairs other functions but is more rapidly taken into the blood stream. For minor wounds the soldier using the inhaler can

[82] Vandre interview.
[83] Details can be found in a report titled *Department of Defense - Executive Agent Responsibilities in Support of Medical Research for Prevention, Mitigation and Treatment of Blast Injuries,* Proceedings, Blast Injury Research Planning Meeting, 10 July 2006, U.S. Army Medical Research and Materiel Command, Fort Detrick, MD.
[84] Vandre interview.
[85] "Built for Battle, Brain Injury Tests May Be Health-Care Boon," *University of Florida News Desk*, 6 February 2003, available at <www.napa.ufl.edu/2003news/headinjurytest.htm>.

sometimes continue on duty.[86] The Army has recently introduced a self-administered pump similar to those used in recovery and intensive care facilities in hospitals. The wounded soldier (if conscious) can control the level of pain in this way. DARPA has a program working with something called an anti-growth factor to develop a treatment for severe trauma, a treatment that will work only at the site of the injury and not in the brain. Thus the medication should not interfere with normal brain functions. The treatment is claimed to be effective for several weeks. One pharmaceutical company is funding trials for registration with the FDA.

- *Treating Infection.* The Army largely leaves development of most medications for the treatment of infection to the pharmaceutical industry. However, the Army is devoting considerable research and development effort to new vaccines for a variety of diseases likely to be encountered by our soldiers. For example, malaria continues to be a very serious problem in Africa. It affects medical teams going in as well as resident populations. An Army vaccine is close to approval. The Bill and Melinda Gates Foundation, working with GlaxoSmithKline, has used this malaria vaccine in field trials.[87] The Army is also working on treatments for the boil-like skin affliction leishmaniasis, which is caused by sand flies and is common in the countries of the Middle East and northern Africa. The Army trials in Algeria suggest that heat application is an effective treatment.[88]

- *Rehabilitation.* There are many challenges in treating and rehabilitating wounded soldiers, particularly amputees and victims of severe burns. DARPA has a major program underway to develop limb prostheses that are fully integrated with the brain.[89] Early models of arms show remarkable progress—amputees can control the prostheses by residual nerves and also can have significantly improved hand function. Much improved power sources (see the section on electronics) for the controlled prostheses are need, though, and there are also problems at the interface between the prostheses and the live tissue that need to be addressed

  Regeneration of lost tissues and bone would of course be the ideal. Long-term developments in the sciences of genetics and new tissue development may one day allow regrowth of lost limbs. Research in regeneration is performed, among other places, at the National Institutes of Health, in the California stem cell research program, and at Wake Forest University. Wake Forest lists 27 different academic institutions that are collaborating with them.[90] MRMC has issued a program solicitation for the formation of an Armed Forces Institute for Regenerative Medicine. The concept is for the private sector to form a consortium to perform the research under a cooperative agreement, much like the basis for the ARL Fed Lab/CTAs.

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[86] Martin interview.
[87] "U.S. Army Joins Forces with Malaria Vaccine Initiative to Launch Clinical Trial in Kenya," *Malaria Vaccine Initiative*, available at <http://www.malariavaccine.org/files/020425-USArmy.htm>.
[88] Glenn interview.
[89] David Pope, "DARPA Prothetics Programs Seek Natural Upper Limb," *Neurotech Business Report*, available at <http://www.neurotechreports.com/pages/darpaprosthetics.html>.
[90] "Extramural/Academic Collaborations," *Institute for Regenerative Medicine*, Wake Forest University, available at <http://www.wfirm.org/extramural_collaborations.htm>.

- *Future possibilities.* From the foregoing we can summarized some developments that will likely succeed and will have considerable effect on survival and rehabilitation. These include:
  - FDA approval for rVIIa for blood clotting
  - FDA approval for Neuren's NN2256 for treating non-convulsive seizures
  - Soldier uniforms that not only monitor physiologic signs but also can apply tourniquet pressure and treat injuries
  - New pain management approaches may allow soldiers to continue their missions
  - New splinting techniques to also allow soldiers to continue with their tasks
  - Advances in managing prostheses to allow for return to duty for more wounded soldiers
  - The ability to regenerate organs and limbs from research in stem cells to make whole wounded soldiers

System Level Battle Command Technologies

In addition to the S&T efforts in electronics, sensors and robotics, we choose to parenthetically mention here that a program manager (PM), such as PM, Battle Command, also works on technology above the maturity level of S&T and efforts are normally at the systems level. Integration and systems engineering are also high priority efforts for PM, Battle Command, as in efforts to standardize and consolidate servers to develop modular server architectures and centralize Battle Command services. Thus, PM, Battle Command is focused on efforts like standardized collaboration, migration to a joint system, and transition to a netcentric enterprise system. The PM, Battle Command has grouped efforts as follows:

- *Battle Command*. Develop commander and "key leader" systems that are configurable and support staff operations.
- *Platforms*. Develop hardware and software for use on tactical vehicles as well as for use by dismounted warfighters, as well as supporting logistics needs.
- *Netcentric BC Server Suite*. Develop enterprise services (e.g., email, security, web portals, data dissemination) and interoperability services (e.g., web applications, C2 data and services)
- *Tactical Networks*. Develop satellite (e.g., JNN, SMART-T) and radio (e.g., LOS, EPLRS) networks, as well as the network operations and firewalls to operate and protect those networks.
- *Tactical Operations Centers*. Develop integrated command post platform infrastructure (e.g., servers, power, switches), environmental control (e.g., air conditioning), tents and shelters.

In attempting to achieve these system-level efforts, capability roadblocks are often encountered and the PM seeks resolution by turning to the S&T community of the Army, other Services, DOD Agencies, industry, and academia; and pursuing Army Technology Objectives (ATOs), Defense Technology Objectives (DTOs), ACTDs, Small Business Innovative Research (SBIRs),

and Technology Transition Initiatives (TTIs). S&T investment leveraging over a five year period (FY05 through FY09) equates to about $403 million of 6.2 and 6.3 funding, broken out approximately as $158 million for C2 technologies, $153 million for network technologies, and $92 million for enabler technologies.

It would become too onerous to list within this report all the system and technology efforts being pursued by PM, Battle Command. Efforts of interest in support of S&R operations include:

- Command Post of the Future (CPOF), discussed in the previous chapter, is being upgraded to include some stabilization-related information like the tracking of and icons for IEDs. CPOF is also benefiting from efforts to develop common operational pictures across all information systems. The integration of reconstruction-related information is not included in updates.
- Communications improvements are being worked closely with the CERDEC to address non-line-of-sight and bandwidth issues. Near term efforts like the WIN-T will provide a high speed, high capacity backbone communications network for brigade combat teams and higher level organizations. WIN-T will also support interoperability with other Service and Joint networks. It will include SATCOM, air-to-ground LOS, ground-to-ground LOS, wireless, cellular, and cable connectivity.
- Effects Based Operations efforts are addressing the much needed integration of DIME activities and PMESII systems into battle command planning and execution, taking into account the language and cultural dimensions of conducting missions in S&R operations. Efforts include the integration of the TEBO ACTD, a U.S. Military Academy developed EBASS, and other DIME/PMESII-based efforts. TEBO is providing some secondary benefits for cross-Service and Joint operations by integrating at the cognitive object level rather than system-to-system database mapping, and providing an open standard architecture for inclusion of Coalition partners.
- Robotic systems are included in the Battle Command vision, and the tactical C2 of robotic systems is being addressed primarily by CERDEC. However, S&R-specific requirements (e.g., UAV air space de-confliction, route planning for unmanned systems, and use in stabilization activities like IED jamming) may not be completed addressed.
- Airspace Management is recognized by PM, Battle Command as a significant problem for current and future operations, especially S&R operations (with its complexity of military and non-military manned and unmanned systems). Currently, there is an inability to maintain situational awareness and positive control of users, so de-confliction is established by using larger separation (lateral, altitude, time) between users. A multi-disciplined, system-of-systems approach is needed to solve the problem, but PM, Battle Command recognizes that current combat development, materiel development, and funding processes are too stovepiped. So PM, Battle Command has established an airspace management working group to seek a multi-discipline, materiel-focused solution.
- Modeling and Simulation tools are being developed or leveraged to support course of action analysis and planning. PEO STRI's One Semi-Automated Forces (OneSAF) Objective System simulation is to be embedded in Battle Command systems to provide course of action analysis support and a capability to assess the progress of a mission execution. An example of a tool development being leveraged by PM, Battle Command is DARPA's Deep Green effort. This tool will continuously monitor the current battle,

predict possible future states, and then proactively create course of action options for the commander – well ahead of the current fight.

- Enhanced Route Planning is another tool which will enhance S&R operations by allowing users to consider many variables, to include PMESII data, when planning a route.
- Dismounted warfighter S&R issues are being addressed by PM, Battle Command in coordination with appropriate labs and other PM shops. Efforts include Battle Command for dismounted warfighters (e.g., the Commanders Digital Assistant, dismountable hardware initiatives), dismounted Blue Force Tracking in urban environments (e.g., networked assisted GPS, pedometer/"dead reckoning" devices, MEMS inertial measurement devices, positioning with range measurements), and tools that will enhance force protection for dismounts (e.g., Ancile – which warns dismounted soldiers about incoming indirect fires).
- Allied/Coalition Interoperability/COP is being addressed with two international agreements – the Multilateral Interoperability Program (MIP) and Artillery Systems Cooperation Activities (ASCA). PM, Battle Command believes there are currently no significant technological barriers to achieving coalition interoperability.
- Multi-level Security is being addressed with Battle Command Cross Domain Solution (CDS), which provides the ability to manually and/or automatically access or transfer information between two or more differing security domains.

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Advances in the science and technology in the technology areas described in this chapter are likely to be very rapid in the next two decades. Solid state physics and electronics have been moving forward at exponential rates since the invention of the integrated circuit. This will continue. Prospects for combat casualty care will brighten as we learn more from neuroscience, from advances in medicines and in the means to apply them, and from such exciting new areas as regenerative medicine. Faster, smaller, and less expensive computer elements and advances in sensors will undoubtedly bring the capabilities of robots close to those of humans with the prospect of substituting them in areas of high hazard. New materials by design, based, in part, on new ideas from nanotechnology, will improve our ability to produce more effective structural materials and light-weight armor both for vehicles and individual soldiers.

Chapter 7. Summary and Concluding Remarks

This report accomplishes several important things with regard to the interface of technology and stabilization and reconstruction operations. First, it updates the observations from SRO(I), a 2006 study on the same subject. Most of these updates pertain to, or border on, the general area of battle command, addressing issues such as tracking friendly forces, integrated S&R operational planning and execution C2 systems, translation devices, and effective communication devices, intelligence gathering, and force protection.

Secondly, it provides an additional look at the technology—S&R picture from an operations research perspective. This allowed not only an in-depth look at the capability gaps discussed in SRO(I) but it enabled additional topics such as combat casualty care to become part of the picture. Specifically, the operations research approach is a use case analysis where the warfighter undertakes sequences of activities to accomplish a goal, which for each use case is an S&R mission. Three such use cases were utilized and analyzed. Warfighters at Fort Benning provided an assessment of this analysis, offering thoughts and commentary based on their experiences in Afghanistan and Iraq. Put broadly, they echoed many of the findings of SRO(I) with respect to the need for improved C2, communications, and ISR capabilities.

Lastly, the report turns to battle command and advanced technologies. With the importance that battle command has played, and will continue to play, in S&R, we have provided a glimpse into current and future thinking and planning on the subject. This glimpse includes discussion of the features of battle command as they are focused on S&R including ISR integration, communications, computer networking, and CPOF.

A comparison of the information we have gathered from returnees from Iraq in 2005, 2006, and most recently from soldiers at Fort Benning reveals consistency in that the interviewees discussed the same gaps in capabilities. Some of the problems are more likely to be solved by technology than others but all have some technical component. For example, additional training needs are being addressed by simulation and longer life of logistics vehicles can be had by improved design. As we progressed through the interviews we were able to gather more details about the problems soldiers are encountering. These details help inform the technical needs. In the following we review and integrate the discussions of the gaps and then conclude with some generalizations.

Summary of Warfighter Comments

In Command and Control the interviews discussed the inability to track and identify dismounted personnel in urban environments. They also wanted the ability to track civilians in situational awareness (SA) systems and would like to see more done on tracking red forces. Subsequent discussions added that tracking in urban areas is generally by voice communications but that they are not reliable because of interferences. Whereas soldiers want all the communications they can get at the unit level about team members and nearby units, they would like to see less data from higher echelons. They worry about information overload; they would like to scale the information that flows both up and down the echelons so that participants get only the

information they need. The other side of this issue is that all this information going up the chain of command enables senior leaders to “reach down” to the lowest levels and creates the potential to override the leader in the field. (This is a problem in the civilian sector as well where a CEO can watch the daily ebb and flow of manufacturing and sales figures and may begin to try to run the entire business from his or her office.) At the assessment sessions at Fort Benning soldiers went so far as to propose a new function at the platoon level – “information overwatch”- to serve as a communication monitor and control point. They suggest the same function might be valuable at company and battalion levels.

Commanders are pleased with the CPOF but want more timely data at battalion level. The Fort Benning participants said they would like to have S&R-related icons for blue, red, and white groups in their SA systems. Commanders strongly endorse Blue Force Tracking and would like to have it for the individual soldier. They would like communications gear to be detachable from command vehicles; want better interoperability among radios; and have needs for organic translators (translators are now attached to upper echelons and usually do not stay with any one unit).

Most of these problems are being addressed in the Army S&T program, for example, improved situational awareness displays and decision aids for commanders. Others need more than technology. Scaling information flow is a problem in deciding who gets what information – a doctrine question. Research is addressing the communications issues by developing more capable, interoperable radios such as the MBITR and JTRS.

In force protection soldiers would like options for body armor depending on assignment; e.g., where agility is less important, more armor could be tolerated and could be extended to arms and legs. New technology for body armor is actively addressed by The Soldier Center at Natick and by the ISN at MIT.

In ISR, long-term or persistence surveillance are desired for monitoring base perimeters, supply sites, and movements of civilian groups While sensor systems for locating mortars and snipers are effective, soldiers are unable to respond rapidly for fear of collateral damage. By the time riflemen are dispatched the targets may well have moved on. This is a doctrine problem primarily. There is a continuing need for “see through the wall” sensors for urban operations. Problems at check points could be eased by better stand-off sensor systems with fewer false positives. Counter IED systems are continually evolving as are the techniques used by the adversaries.

The Army has robust research and development programs in sensors and sensor systems. There are programs in thermal sensors, radar and ladar, data fusion and reduction on the sensor, distributed sensor systems, new sensors for detecting explosives and biologic agents, and many others. These programs are addressing the issues listed above.

Interviewees agree on several issues relating to UAVs including the need for persistent viewing, stealth performance, and lower cost. Downloading information from UAVs is slowed by limits on bandwidth. For unmanned ground vehicles, soldiers would like to be able to use robots for explosive detection at check points. An interesting comment at Fort Benning was concerning the

speed at which robots can operate. In scouting assignments in urban areas, for example, soldiers don't want to wait around very long for the robot to do its job because that waiting may place the soldiers in harm's way.

The S&T program on unmanned vehicles is conducted at DOD, DARPA, and the services. As unmanned vehicles become more capable due to advances in power sources, in miniaturization of electronic devices, and in computing, they will be able to perform the tasks now considered too hard. Thus the speed with which a UGV can reconnoiter in urban settings will become faster and faster with time. The time to download data from UAVs will be reduced by more on-sensor fusion and analysis as well as new techniques to improve utilization of bandwidth.

Soldiers are concerned that in conducting S&R operations they may be losing their core skills; e.g., that artillery men are by and large given artillery assignments and don't have opportunity for regular training. One possibility is more use of simulators in the field to hone skills.

Soldiers at Fort Benning brought up the subject of battlefield medicine. In particular they would like sensors to provide the status of individual soldiers and beacons to show where they are. This was the only instance where soldiers raised the medical question, suggesting either that they don't know much about it or they are relatively satisfied with the progress that has been made. (On the other hands the medics themselves see a number of challenges – see Chapter 6.)

A summary of the capabilities and technologies that address these needs is shown in figure 6, while a more detailed version may be found in Appendix B.

	Command & Control	Comms	Computers	Intelligence	Surveillance	Recon	Force Protection	Unmanned Systems	Combat Care	Other
Electronics	●	●	●	●			○	●	●	○
Sensors	●			○	●	●	●	●	●	○
Materials			○				●	●		
Power Sources	○	○	○		○		○	●	○	
Robotics						○	○	●		○
Battle Command	●	●	●	●	●	●	●	●	●	●
Combat Medicine									●	

● = Strong Support ○ = Moderate Support

Figure 6. Technologies – Capabilities Mapping Summary

Concluding Remarks

The foregoing description of the interviews leads one to a few broad themes:

- Concerns about battlefield information – quantity and quality and the need to scale the amount of information passed,
- Need for more capable and versatile sensors and sensor systems
- Need for simplicity and user friendliness of Army systems,
- Needed improvements in unmanned systems.

SRO(I) and the data collected in this report leave no doubt that the Army's S&R capabilities can be improved. While not all solutions to current issues are technical, current and future technology development are central to improving these capabilities. Chapter 6 provides assessments of the state-of-the-art in the important technology areas of electronics, sensors, power sources for the individual soldier, basic research in advanced materials, robotics, combat casualty care, and system level battle command technologies.

It will take careful planning and management to translate advances in these promising technology areas into useful capabilities for S&R and other Army missions. The S&T base must remain responsive to the needs of warfighters in the field. Army-funded exploration of nanotechnology, biological phenomena, and the like, should be informed by analysis of needs for additional capabilities. Tools such as Army Strategic Research Objectives help to forge this link.[91] Strategic Research Objectives have been designed to focus the Army's basic research program. These multidisciplinary research themes, including subjects like Nanoscience and Armor and Materials by Design, direct special attention and outline specific research goals for particularly promising areas. In this way the resources of the Army research community can be harnessed to meet the needs of forces in the field, for S&R operations and beyond.

[91] *Army Science and Technology Master Plan 2005*, Volume I, U.S. Department of the Army, Office of the Assistant Secretary of the Army for Acquisition, Logistics, and Technology, V-28.

APPENDIX A: ACRONYM LIST

A2C2S	Army Airborne Command and Control System
ABCS	Army Battle Command System
ACTD	Advanced Concept Technology Demonstration
AFATDS	Advanced Field Artillery Tactical Data System
AMDWS	Air and Missile Defense Workstation
AN/PRC	Army/Navy, Portable Radio Communication
AO	Area of Operations
ARL	Army Research Laboratory
ASAS	All-Source Analysis System
BATS	Biometric Automated Toolset
BC	Battle Command
BCBL	Battle Command Battle Laboratory
BCOTM	Battle Command on the Move
BCS3	Battle Command Sustainment and Support System
BCT	Brigade Combat Team
BFT	Blue Force Tracker
BNTOC	Battalion Tactical Operational Center
C2	Command and Control
C4	Command, Control, Communications, and Computers
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CAC	United States Army Combined Arms Center
CBRN	Chemical, Biological, Radiological, and Nuclear
CCIR	Commander's Critical Information Requirements
CERDEC	United States Army Communications – Electronics Research Development and Engineering Center
COA	Course of Action
COIN	Counterinsurgency
COMPOEX	Conflict Modeling, Planning, and Outcomes Experimentation
COMSEC	Communications Security
CONUS	Continental United States
COP	Common Operating Picture
COTS	Commercial-Off-the-Shelf
CPOF	Command Post of the Future
CTA	Collaborative Technology Alliance
CTNSP	Center for Technology and National Security Policy, National Defense University
DARPA	Defense Advanced Research Projects Agency
DIME	Diplomatic, Information Operations, Military, and Economic
DISN	Defense Information System Network
DMSO	Dimethylsulfoxide
DOCEX	Document Exploitation
DOD	Department of Defense
DOTMLPF	Doctrine, Organization, Training, Materiel, Leadership and education, Personnel, and Facilities

DSN	Defense Secure Network
DTSS	Digital Topographic Support System
EBASS	Effects-Based Assessment Support System
EOD	Explosives Ordnance Disposal
EPLRS	Enhanced Position Location Reporting System
FBCB2	Force XXI Battle Command, Brigade and Below
FCS	Future Combat System
FDA	Food and Drug Administration
FM	Field Manual
FPA	Focal Point Array
GCCS-A	Global Command and Control System – Army
GC/MS	Gas Chromatography / Mass Spectrometry
HIFU	High Frequency Focused Ultrasound
HMMWV	High-Mobility Multipurpose Wheeled Vehicle (Humvee)
HUMINT	Human Intelligence
ICAF	Industrial College of the Armed Forces, National Defense University
ICB	Institute for Collaborative Biotechnology
ICT	Information and Communications Technology
IO	Information Operations
IED	Improvised Explosive Device
IEDM	Information Exchange Data Model
IMETS	Integrated Meteorological System
IMINT	Imagery Intelligence
IR	Infrared
ISAF	International Security Assistance Force
ISN	Institute for Soldier Nanotechnology
ISVN	Interim Secure Voice Network
JC3IEDM	Joint Consultation Command and Control Information Exchange Data Model
JIIM	Joint Interagency, Intergovernmental, and Multinational
JLENS	Joint Land-Attack Cruise Missile Defense Elevated Netted Sensor System
JNEM	Joint Non-kinetic Effects Model
JROC	Joint Required Operational Capability
JTRS	Joint Tactical Radio System
LADAR	Laser Detection and Ranging
LOS	Line of Sight
M&S	Modeling and Simulation
MBITR	Multiband Inter/Intra Team Radio
MCS	Maneuver Control System
MDMP	Military Decision-Making Process
MEMS	Microelectromechanical System
METT-T	Mission, Enemy, Terrain, Troops, and Time
MIT	Massachusetts Institute of Technology
MOUT	Military Operations in Urban Terrain
MRMC	Army Medical Research and Materiel Command
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization

NCES	Network-Centric Enterprise Services
NDU	National Defense University
NECC	Net Enabled Command Capability
NGO	Non-Governmental Organization
NLOS	Non-Line-of-Sight
NWC	National War College
OPTEMPO	Operational Tempo
PDSS	Pre-Deployment Site Surveys
PLGR	Precision Lightweight Global Positioning System Receiver
PM	Program Management
PMESII	Political, Military, Economic, Social, Information and Infrastructure
PRT	Provincial Reconstruction Team
QWIP	Quantum Well Infrared Photodetectors
ROE	Rule of Engagement
S2	Intelligence Officer (battalion level)
S&R	Stabilization and Reconstruction
S&T	Science and Technology
SATCOM	Satellite Communications
SBCT	Stryker Brigade Combat Team
SERS	Surface Enhanced Raman Scattering
SIGINT	Signals Intelligence
SINCGARS	Single Channel Ground and Airborne Radio System
SOF	Special Operations Force
SRO(I)	*Army Science and Technology Analysis for Stabilization and Reconstruction Operations*, Defense & Technology Paper 37, precursor to this paper
SRO(II)	*A Further Look at Technologies and Capabilities for Stability and Reconstruction Operations* (current paper)
STAR	Strategic Technologies for the Army
TAIS	Tactical Airspace Integration System
TCP	Traffic Control Point
TEBO	Theater Effects Based Operations
TOC	Tactical Operations Center
TTPs	Tactics, Techniques, and Procedures
TRADOC	Army Training and Doctrine Command
UAV	Unmanned Aerial Vehicle
UA/VE	User Assessment / Validation Exercise
UGV	Unmanned Ground Vehicle
USA	United States Army
USAF	United States Air Force
USMC	United States Marine Corps
VOIP	Voice Over Internet Protocol
VTC	Video Teleconference
WIN-T	Warfighter Information Network - Tactical

APPENDIX B: TECHNOLOGIES – CAPABILITIES MAPPING DETAILS

Technologies Of Interest \ Capability Needs	Command & Control							Communications						Computers				Intel		Surveillance						Recon		Force Protection						Unmanned Systems									Cbt Care			Other				
	NLOS BCOTM	Track Blue, Red, White	Track Dismounts	Multilevel Security	Control Info Overload	Integrate EBO/PMESII	Integrate Reconstruction	Interoperable w/ US Mil	Interoperable w/others	Small Unit Comms	Portable from Vehicles	Better NLOS in Urban	Language Translation	Voice Input to Screens	Handheld Civ ID Device	Portable Vehicle C2 Sys	3-D Visualization	Improved Info Collection	DBs of Susp Persons	Persistent Surveillance	Pattern Recognition	Rapid Access to UAVs	Through Wall Sensing	Detect Bombers at TCP	Standoff IED Detection	Dynamically Track C4s	Remote Reconnaissance	Personnel/Veh Protection	Light Agile Body Armor	Secure Base Perimeters	Surveillance of MSRs	Counter-mortar/sniper	CB/Indust Chemicals	Min Human Intervention	Data Storage/Download	Long Duration UAVs	Low Signature UAVs	Low Cost UAVs	Airspace De-confliction	UGVs at Checkpoints	Faster, Agile UGVs	Search Bldgs/Rooms	Physiological Monitoring	Head/Arm/Leg Wounds	Location of Casualties	Too Much To Do	Reach Down	OPTEMPO	Fielding New Tech/Sys	Maintain Cbt Readiness
Electronics																																																		
• Processors	●	O	O		●			O	O	O	●		●	●	●	●	●	O	●		●	●				O				O	O	O		●	●			O	O			●	●			O				
Sensors																																																		
• Fusion at the sensor					●													O		●	●		●			●	●			●	●	●	●		O							●	●			O				
• Multi-function		●																		●	●		●	●	●	●	O			O	O	O	●										●							
• Multi-spectral																				●	●		●	●	●		O			O	O	O																		
• Defensive sensors																									●			●				●																		
• Chem sensors																									●		O	O					●																	
• Quantum dot																											O	●																						
• Bio sensors		●																								O	O	O					●																	
• HEL sensors																							●		●		O																							
Materials																																																		
• Materials by design																												●	●								●	●												
• Modeling w/HPCs																												●	●								●													
• Nanotechnology																												●	●																					
• Biotechnology															O													●	●				O				O													
• Body armor																												●	●																					
Power Sources																																																		
• Small, light batteries	O									O	O				O					O								O			O					●									O					
• Solar power	O									O	O									O								O			O					●														
• Bio electrodes										O	O									O								O																						
Robotics																																																		
• Enhanced robots																										O	O			O	O		O	●												O				
• Soldier-robot teams																																		●																
• Autonomous																														O	O		O	●												O				
Battle Cmd Tech																																																		
• Enhanced CPOF							O															O																												
• Improved Comms	●							●	●	●	●	●										O																							●		O			
• EBO/PMESII						●																																												
• Robotic systems																																		●						O	O	O								
• Airspace mgmt																						●																	●											
• M&S	O					O																																												●
• Route planning						O										●	●																																	
• BC for dismounts											●	O		●		●	●																														O			
• Dismount BFT		●	●																							O																			●					
• Force protection			O																									●				●																		
• Interoperability/COP	●						O	●	●								●																														O			
• Multi-level security				●			O	●	●									●	●	O																											O			
Cbt Casualty Care																																																		
• Control bleeding																																												●						
• Brain injuries																																												●						
• Medical sensors																																											●	●	●					
• Pain Management																																												●						
• Treat infection																																												●						
• Rehabilitation																																												●						

● = Strong Support O = Moderate Support

APPENDIX C: DETAILED RESULTS OF USE CASE ANALYSIS

Battle Command

1. Modular design of command posts that allows them to be easily moved out of vehicles into buildings, operate in a distributed battle command environment, and use local/renewable power sources
2. Ability to synchronize combat, humanitarian assistance, and S&R operations, potentially simultaneously
3. Timely collaboration and coordination among Service, Joint, government agency, and coalition forces
    a. To include use of multi-level security chat rooms and VTCs
4. The integration and visualization of reconstruction operations as part of the COP for daily stabilization operations
5. The integration and visualization of PMESII data as part of the COP for daily stabilization operations
    b. To support effects based operations
    c. To support the planning and execution of tactical operations
6. Interoperable communications among U.S. military and non-military organizations, foreign military and non-military organizations, and others
7. Ability for rapid sharing of information with coalition members, multiagency members, and non-government organizations
8. Ability to visualize 3D operations with PMESII overlays and well conceived rules of engagement
9. Ability to track entities or activities that are normally not tracked or are normally tracked in small numbers—e.g., scaling up to track thousands of civilians who are conducting day-to-day activities
10. The deconfliction of air space for use of UAVs by battalion and below force elements
11. Ability to coordinate fires (Joint through subordinate organic) in a netcentric environment that is severely constrained by rules-of-engagement and urban obstructions to trajectories of munitions
12. Immersive computer systems for mission planning, rehearsal, and execution
13. Embedded M&S tools for identifying benchmarks for operations and conducting "what-if" activities
14. The ability to command, control, and communicate with units operating in environments where today's radios and GPS systems work poorly

Small Unit Operations

1. Persistent blue force tracking for all personnel, including visualizing 3D location of all forces in complex environments above and below ground
2. Mobile immersive computer systems for dismounted personnel for visualization, planning, rehearsal, execution, and information overwatch
3. Secure Instant Messaging/Text Messaging
4. Presentation of 3D representation of area of interest, including PMESII data
5. Multiband BLOS radio capable of secure voice and broadband data links
6. Automated decision analysis tools that support distributed, collaborative planning
7. M&S-enabled course of action (COA) planning and analysis tools

8. Tools for identifying platoon and lower objectives
9. Tools for coordinating non-linear actions in a complex urban environment
10. Hands-free use of information systems during assault
11. Ability to develop/modify plans in real time

Battlespace Awareness

1. Persistent situational awareness (in 3D) through all aspects of S&R operations and at all echelons
2. Total asset awareness—location and identification of U.S. forces, non-U.S. forces, local police forces, non-DOD assets, etc. Note: in S&R operations the availability of these assets changes daily, unlike in combat operations where a commander knows what assets are tasked to him in direct support
3. Persistent tracking of blue, red, and white entities in AO
4. Rapid, accurate battle damage assessments from all blue and red activities, taking into account effects based operations (including PMESII data)
5. Visualization of reconstruction activities in the area
   a. For example, schedule of reconstruction material convoys near or through areas of operation
6. Weather information that is significant for the operation
   a. Especially wind speed and directions in urban canyons
7. M&S-enabled visualization systems
8. Ability to rapidly gather, fuse, and display 3D terrain and feature data
9. Ability to view available data (from sensors, archives, commercial data) on each building/structure in the area of operation—floors, rooms, construction materials, etc.
10. Real-time visualization of dynamic terrain (e.g., rubble from a recent strike)
11. Predictions to changes in terrain
12. Identify fields of fire (in 3D)
13. Inter-visibility and interference for NLOS weapons
14. Identify cover and concealment
15. Identify obstacles
16. 3D visualization of weapons availability
17. Null-out of blue forces and known civilians from sensor data
18. Selection of best entry point into a room
19. Visualization of likely enemy locations (including for snipers and IEDs)

Intelligence, Reconnaissance, and Surveillance

1. Persistent surveillance systems
2. See-through-wall sensing
3. Temporary networked sensor systems (e.g., smart sensor web distributed by air/land)
4. Creation/availability of actionable intelligence
5. Ability to send/receive imagery from battalion down to fire team leaders
6. Access to military and non-military intelligence information from both U.S. and non-U.S. sources
7. Knowledge of and location of intelligence gathering systems in the area (ground based sensors, UAVs, HUMINT, satellite imagery, etc.)

8. Availability of launching ISR systems in real time—self-configuring sensor networks, unmanned systems, etc.—or tasking national assets
9. Identify and track insurgents, vehicles, and weapons (including IEDs)
10. Identify and track civilians of interest
11. Identify insurgent-civilian interactions
12. Historical data/trends of insurgent activity in the area, including ability to identify why an activity (e.g., abduction) may have occurred
13. Understanding of future enemy actions—for example, sensors that sense enemy intentions.
14. Impact of culture on enemy actions
15. Detection of CBRN, including toxic chemicals
16. Information on controls for electric power and other utilities to the target area
17. Sensors which sense and track individual personnel in a group
18. Establishment of perimeter security, with checkpoints
19. Remote 3D sensing of area of operation (including sensor networks, UGVs, UAVs)
20. Sensors for monitoring cleared areas

Force Application

1. Tools that identify impact of tasking battalion resources to support a mission
2. Simulations that provide "what ifs" based on outcome of actions
3. Tools/technologies that may be able to "free up" resources to support battalion operations (e.g., augment some scheduled manned missions with unmanned systems)
4. Automated tools for identifying protected, covered, and concealed movement
5. 3D entry into and extraction from buildings (including ability to enter buildings other than through 1st floor doors & windows)
6. Secured movement
7. Rapid retrieval of all equipment (including sensors)
8. Ability for small units to task, coordinate, and control non-organic assets
9. Optimal selection of weapons (lethal and non-lethal), vehicles, and personal equipment for mission
10. Ability to coordinate non-linear assault with support from non-military assets
11. Call-for-fire tools that take into account weapon system and interference issues

Force Protection

1. Lightweight, full body, personal protection systems
2. Advanced vehicle/personnel protection from blast
3. Mobile TCPs
4. Mobile screening systems
5. Ability to block all traffic (above and below ground) and communications in and around an AO

Unmanned Systems

1. Integration of unmanned systems (hands free and immersed control of systems)
2. Control of unmanned systems in support of assault (including micro unmanned systems)
3. Use of robotics at TCPs
4. Use of robotics at observation points

5. Interaction of robots with local populace—e.g., implementation of rules of engagement
6. Obstacle avoidance capabilities
7. Use of robotic systems in reconstruction and logistics activities

Non-Lethal Capabilities

1. Hands-free use of non-lethal weapons
2. Rapid transition from non-lethal to lethal weapons
3. Focused non-lethal capabilities that do not harm/interfere with blue force systems

Information Operations

1. Information dissemination tools
2. Tools that block insurgents from distributing their propaganda (e.g. cell phone jamming, jamming of video recorders)
3. Language translation tools
4. Rapid direct access to all local religious, social, and political leaders
5. Rapid access to array of reliable media, especially local but also global
6. Tools for mapping cultural data (location of religious sects, identification of religious/historical buildings, etc.)
7. Availability of historical data on cultural activities

Logistics

1. Long range communications for long haul logistics
2. Ability to coordinate movement and support from reaction forces while traveling through numerous unit sectors
3. Rapid integration of host nation assets
4. Ability to provide long-duration power systems to blue forces which will operate away from typical military sources of power

Combat Medicine

1. Commander's and corpsman's knowledge of individual health and morale
2. Rapid medical attention to casualties
3. Enhanced capabilities for treating blast and burn victims
4. Ability to rapidly identify and diagnose brain trauma
5. Ability to detect medical emergency for warfighter separated from other unit personnel
6. Advanced capabilities for reducing bleeding
7. Early identification of heat injuries
8. Ability to deal with a local populace and/or opposing force which may have wide-area infection of a disease such as HIV

Mitigation of Collateral Damage

1. Non-lethal weapons
2. Very high resolution target ID systems
3. Mobile triage systems
4. Precision munitions
5. Integration of reconstruction assets

Reconstruction

1. Making area safe (e.g., EOD) for returning civilians
2. Rapid repair of damaged structures and utilities
3. Ability to train and utilize local assets

Training

1. Tools for rapidly training personnel for S&R operations (e.g., rebuilding a town)
2. Tools for rapidly educating personnel on cultural diversity issues
3. Tools for maintaining combat efficiency while conducting long-duration S&R operations